BSC	Design Calculation or Analysis Cover Sheet *Complete only applicable items.*	1. QA: QA 2. Page 1 of 60

3. System	4. Document Identifier
Emplacement and Retrieval	800-MQC-HE00-00100-000-00C

5. Title

Transport and Emplacement Vehicle Envelope Calculation

6. Group

Subsurface Engineering / Mechanical

7. Document Status Designation

☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled ☐ Superseded

8. Notes/Comments

This version supports closure of CR-12533. Pages 6, 7, 10, 14, 18, 21, 23, 26 through 30, 33 through 38, 45 through 47, 51, 52, and 59 revised. The changes in these pages were marked with change bars. The following revisions were made:

1. Section 6.3.3 is revised since the sin function calculation used radians instead of degrees in the previous version. This resulted in an incorrect number and corresponding errors for subsequent use Section 6.3.5, Section 6.4.3 and Section 6.6.3. These sections are revised accordingly.
2. Other editorial changes made in Section 4.2, Section 6.2.1 and Section 6.3.4.
3. Assumption 3.2.2; factor of safety for weight is changed to "factor of safety for lift weight" since the weight operational allowance (Section 3.2.17 and 3.2.18) has already added in the calculation.
4. Add Reference 2.2.14 and Reference 2.2.15.

Attachments	Total Number of Pages
Attachment 1 – Conceptual Sketch to Indicate TEV Major Components	1
Attachment 2: One CD including MathCAD file: TEV MEE Calculation.xmcd	N/A

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Initial issue	60	60	Matthew Voegele 3/12/2007	Kenneth D. Draper 3/12/2007	Thornley, Robert A. 3/12/2007	H. Jalali / O. Asuncion 3/12/2007
00B	Resolve CR-10748 and 10857. Incorporate the TMRB Decision Proposal and the revised design values.	60	60	Kenneth D. Draper 08/28/2007	Matthew Voegele 08/28/2007	Thornley, Robert A. 08/28/2007	Hadi Jalali 08/29/2007
00C	See notes in block 8	60	60	Huajun Chen Huajun Chen 11/06/2008	Steve Simner S. Simner 11/10/2008	Edward Thomas Edward Thomas 11/10/08	Edward Thomas Edward Thomas 11/10/08

DISCLAIMER

The calculations contained in this document were developed by Bechtel SAIC Company, LLC (BSC) and are intended solely for the use of BSC in its work for the Yucca Mountain Project.

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ACRONYMS AND ABBREVIATIONS

BSC	Bechtel SAIC Company, LLC
DOE	U.S. Department of Energy
SAIC	Science Application International Corporation
TAD	transportation, aging, and disposal (canister)
TEV	transport and emplacement vehicle
TMRB	Technical Management Review Board
WP	waste package

1 PURPOSE

The purpose of the *Transportation and Emplacement Vehicle Envelope Calculation* is to estimate the following:

- Shielded enclosure envelope dimensions
- Shielded enclosure weight
- Beam size for the TEV chassis
- Lift mechanism capacity
- Total weight of TEV both loaded and unloaded
- Horizontal drive capacity
- Overall envelope for TEV with doors open and doors closed.

2 REFERENCES

2.1 Procedures / Directives

2.1.1 BSC 2007. EG-PRO-3DP-G04B-00037, Rev. 13, *Calculations and Analyses*. Las Vegas, Nevada. Bechtel SAIC Company. ACC: ENG.20080922.0005.

2.2 Design Inputs

2.2.1 AISC (American Institute of Steel Construction) 1997. *Manual of Steel Construction, Allowable Stress Design*. 9th Edition, 2nd Revision, 2nd Impression. Chicago, Illinois: American Institute of Steel Construction. TIC: 240772 (ISBN 1-56424-000-2)

2.2.2 ASME NOG-1-2004. 2005. *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)*. New York, New York: American Society of Mechanical Engineers. TIC: 257672 (ISBN 0-7918-2939-1)

2.2.3 Avallone, E.A. and Baumeister, T., III, eds. 1987. *Marks' Standard Handbook for Mechanical Engineers.* 9th Edition. New York, New York: McGraw-Hill. TIC: 206891 (ISBN 0-07-004127-X)

2.2.4 BSC (Bechtel SAIC Company) 2003. *Emplacement Pallet Configuration.* 000-M00-TEP0-00102-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20031006.0004.

2.2.5 BSC 2003. *Underground Layout Configuration*. 800-P0C-MGR0-00100-000-00E. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20031002.0007.

2.2.6 BSC 2006. *Conceptual Shielding Study for Transport Emplacement Vehicle.* 000-30R-HE00-00100-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20060911.0001.

2.2.7 BSC 2008. *Basis of Design for the TAD Canister-Based Repository Design Concept.* 000-3DR-MGR0-00300-000-003. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20081006.0001.

2.2.8 BSC 2007. *Drift Cross Section Showing Emplaced Waste Package and Drip Shield*. 800-M00-WIS0-00101-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070412.0003.

2.2.9 BSC 2007. *TMRB Decision Proposal, Activities Not to Preclude Handling of South Texas Commercial Spent Nuclear Fuel in the Surface Facilities*. TMRB-2007-025. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20070720.0045.

2.2.10 BSC 2007. *Waste Package Envelope Dimensions for Facilities and Handling.* 000-B20-MGR0-00101-000-00B. Las Vegas, Nevada. Bechtel SAIC Company. ACC: ENG.20070321.0011.

2.2.11 Cummins, A.B. and Given, I.A. 1973. *SME Mining Engineering Handbook.* Two volumes. New York, New York: Society of Mining Engineers, American Institute of Mining, Metallurgical, and Petroleum Engineers. TIC: 210125 (Library of Congress Catalog Card Number 72-86922)

2.2.12 SEW-Eurodrive. 2000. *Constant Speed Gearmotors R/F/K/S*. Lyman, South Carolina: SEW-Eurodrive. TIC: 249572.

2.2.13 Pow-R-Jac. *POW-R-JAC Catalog: Lift System Design Manual #800-10000*. Lynchburg, Virginia: Pow-R-Jac Division of Limitorque Corporation. TIC: 239720.

2.2.14 BSC 2007. *Dose Rate Calculation for Transport and Emplacement Vehicle.* 800-MQC-HE00-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071101.0012.

2.2.15 BSC 2007. *Project Design Criteria Document.* 000-3DR-MGR0-00100-000-007. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071016.0005.

2.3 Design Constraints

None

2.4 Design Outputs

2.4.1 BSC 2007. 800-MJ0-HE00-00101-000-00B. *Emplacement and Retrieval Transport and Emplacement Vehicle Mechanical Equipment Envelope.* Las Vegas, Nevada: Bechtel SAIC Company.

3 ASSUMPTIONS

3.1 Assumptions Requiring Verification

3.1.1 Shielding Profile

Assumption: The shield profile described in *Conceptual Shielding Study for Transport Emplacement Vehicle* (Reference 2.2.6) is assumed to be adequate shielding for the transport and emplacement vehicle.

Rationale: *Conceptual Shielding Study for Transport Emplacement Vehicle* (Reference 2.2.6) was written specifically for the TEV. Until the shielding Calculation becomes finalized it must be used as an assumption

3.1.2 Longest Waste Package

Assumption: The "South Texas" waste package is 248 inches in length.

Rationale: Since the *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.7) does not include information regarding the "South Texas" waste package, the approved Technical Management Review Board (TMRB) Decision Proposal is the best available source. The approved *TMRB Decision Proposal, Activities Not to Preclude Handling of South Texas Commercial Spent Nuclear Fuel in the Surface Facilities* (Reference 2.2.9, Bullet 7) states the length of the "South Texas" waste package length is 248 [in.].

3.2 Assumptions Not Requiring Verification

3.2.1 Moving Component Clearance

Assumption: A clearance of two inches is used for the following interfaces:

- Between the shielded enclosure and the frame, see Figure 1.
- Between the waste package and the inside of the shielded enclosure (side and rear) walls, see Figure 1.
- Between the waste package and the inside of the shielded enclosure roof, while loading and unloading, see Figure 1.
- Between the waste package and the inside of the shielded enclosure doors.
- Between the shielded enclosure side walls and the nuclear facility floor/emplacement drift invert for waste package loading or unloading, see Figure 1.
- Between the emplacement pallet and the shielded base plate, see Figure 1.
- Between the shielded base plate and the top of rail

Rationale: A clearance of two inches allows loading and unloading of the TEV without contacting the waste package. Additionally, a clearance of two inches between the shielded enclosure and the frame allows for proper operation of the shielded enclosure lifting mechanisms.

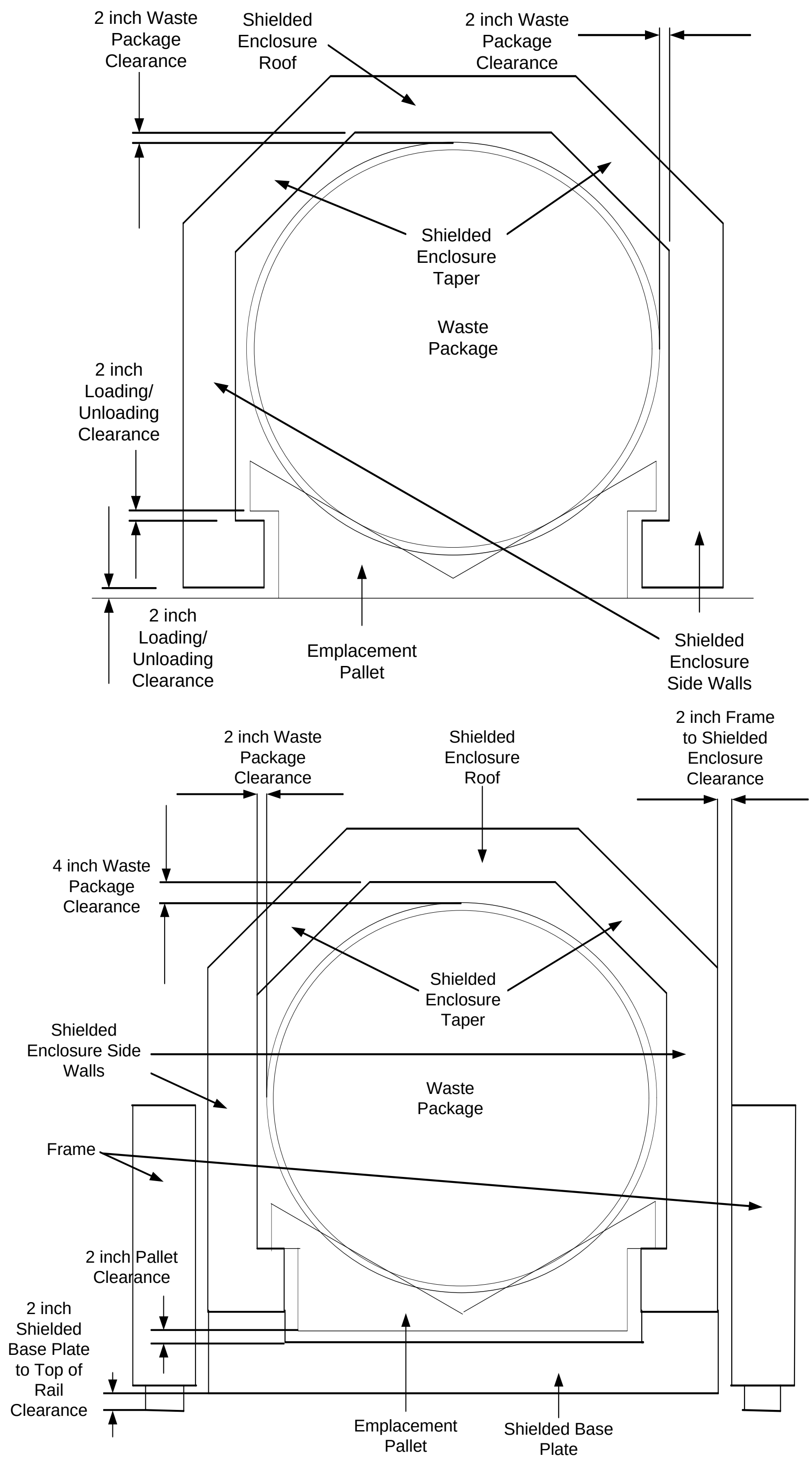


Figure 1: Clearances

3.2.2 Factor of Safety for Lift Weight

Assumption: A 10 % factor of safety will be used for the Lift Weight.

Rationale: According to *Project Design Criteria Document* (Reference 2.2.15, Section 4.8.1.2.5), rerated lifting equipment shall be given a dynamic load test over the full range of lift using a test weight at least equal to 110% of the lift weight.

3.2.3 Shielding Shape

Assumption: The upper portion of the sides of the shielding will be tapered. The "Shield Taper" side will be tapered 45 degrees.

Rationale: The shield taper reduces the TEV shielding weight and minimize materials used.

3.2.4 Worst Case TEV Chassis Loading Scenario

Assumption: The worst-case chassis beam loading scenario occurs when the TEV performs an off-normal lift. During an off-normal lift the TEV will be capable of only using the center two lift mechanisms.

Rationale: This assumption creates a bounding simply supported, center loaded beam scenario for the TEV chassis.

3.2.5 Lift Mechanism Spacing

Assumption: The main lift mechanisms will be spaced 80 inches on each side of the shielded enclosure center of gravity. The two off-normal lift mechanisms will be located at the shielding center of gravity.

Rationale: This configuration allows for proper operational and maintenance spacing between normal and off-normal lifting mechanisms.

3.2.6 Wheel Block Spacing and Size

Assumption: The center of the TEV wheel blocks will be located directly underneath the four main lifting mechanisms. For beam sizing, the wheel blocks will be treated as a point load.

The dimensions of the wheel blocks are 86 [in.] in length, 36 [in.] in height (without the wheel), 40 [in.] in height (with the wheel), and 14 [in.] in width. A clearance of 2 inches is used around the wheel block.

The pivot fabrications are constructed using 2-inch thick steel plates. The side plates are welded to the top plate, which is mounted to the bottom face of the main chassis beam. The side plates straddle wheel block assembly, connecting to the wheel block through a pin. The wheel block pivot fabrication is 88 [in.] in length and 37 [in.] in height.

Rationale: This configuration minimizes the bending moments in the main chassis during normal lifting operations.

The width allows for an 8 [in.] wheel width (Assumption 3.2.16), 1 [in.] clearance either side of the wheel, and a 2 [in.] thick plate mounted either side of the wheel. The length allows for 2-36 [in.] diameter wheels (Assumption 3.2.16), a pivot pin mounted between the wheels, and clearances.

3.2.7 Shape of TEV Chassis Beam

Assumption: The TEV chassis beam will be constructed as follows:

The main chassis beam will be constructed from nominal 1.5 [in] steel plate, and will be a square tubing beam with the dimensions of 20 [in] by 20 [in] and mounted on either side of the shielded enclosure.

Additionally, three chassis legs are fabricated to the main chassis beams located at the front, center, and rear. These legs are fabricated with plates (or feet) mounted to the bottom surface of the legs. The feet have a width of 26 [in.] and a top of rail clearance of 2 [in.].

Furthermore, the chassis has three cross beams. One cross beam is located between the shielded enclosure and the electrical enclosure. The beam is an H-section; the side plates are 25.5 [in.] in height, 1.5 [in.] thick and connects the side frames. The center plate is 11 [in.] in width and 1.5 [in.] thick. The other crossbeams are located in the front and back of the vehicle connecting the side frames. The crossbeams are a simple 10 [in.] by 10 [in.] box-section with 1 [in.] thick walls.

Rationale: The beam size and steel plate thickness will be confirmed later in this calculation. The width of the feet are 3 [in.] wider than the chassis beam width to aid the recovery during a derailment. The crossbeams are used to connect the two side frames. The actual size of these beams will be determined in detail design.

3.2.8 Rail Properties

Assumption: Top of rail is assumed to be 6 [in] above the invert.

Rationale: This value is normal for industry use for 171 [lb.] rail, which is expected to be the rail weight used for the TEV.

3.2.9 TEV Door Hinge

Assumption: Assume that the door hinge will add an additional 5 inches to the TEV overall length

Rationale: The specific door hinge design will be determined during detail design; however, 5 inches creates a conservative bounding condition. Additionally, the 5 inches is half the shielding thickness.

3.2.10 Motor Weight – Lifting

Assumption: A gear motor with sufficient capacity to drive the lift mechanisms, both normal and off-normal, needs to provide an input torque of 15,552 lb.-in (1296 ft-lb.) for a 150-ton jack and 6,900 lb.-in (575 ft-lb.) for a 100-ton jack (Assumptions 3.2.13 and 3.2.14). The closest gear motor to this in the vendor catalogues that were searched that delivers the required input torque is a parallel helical gear unit with a 12.5 [hp] motor. The weight of the normal lift 12.5 [hp] gearbox and motor is about 400 [lb.]. The weight of the off-normal lift 12.5 [hp] gearbox and motor is about 600 [lb.].

Rationale: Consulting the SEW-Eurodrive (or equivalent) catalogue, the models DV132ML4 AC-motor and R87 gearbox are selected for the normal lift. The selected motor and gearbox is a 12.5 [hp] with an output speed of 91 [RPM] and a torque of 8,650 [lb.-in]. Additionally, the motor and gearbox with brake weighs (291 [lb.] + 55 [lb.]) 346 [lb.], rounded up to 400 [lb.]. The models DV132ML4 AC-motor and R107 gearbox are selected for the off-normal lift. The selected motor and gearbox is a 12.5 [hp] with an output speed of 49 [RPM] and a torque of 16,000 [lb.-in]. The motor and gearbox with brake weighs (503 [lb.] + 55 [lb.]) 558 [lb.], rounded up to 600 [lb.] (Reference 2.2.12, Pages 66 and 130). Confirmation of the motor and gearbox selection is determined later in the calculation. For sizing purposes in this calculation, a 12.5 [hp] motor is used; however, the lifting mechanisms in Assumptions 3.2.13 and 3.2.14 are limited to 11.7 [hp]. Therefore, the motor may be de-rated or a smaller motor selected during detail design.

3.2.11 Drive System Motor and Gearbox

Assumption: The drive motor for the TEV is assumed to have the following properties:

Weight is about 1,000 [lb.].
Gearbox Efficiency of 0.94.
Gearbox width is 15 [in.].

Rationale: Consulting the SEW-Eurodrive (or equivalent) catalogue, the models DV160L4 AC-motor and KAF107 gearbox are selected. The selected motor and gearbox is a 20 [hp] with an maximum output speed of 17 [RPM] and a maximum torque of 72,200 [lb.-in]. Additionally, the motor and gearbox with brake weighs (822 [lb.] + 93 [lb.]) 915 [lb.], rounded up to 1000 [lb.]. Furthermore, the selected motor and gearbox has an efficiency of 94% (bearing efficiency is considered negligible) (Reference 2.2.12, Pages 10, 294, 344, 376-377). Confirmation of the motor and gearbox selection is determined later in the calculation.

3.2.12 Constants Used for Tractive Effort Calculation

Assumption: The following constants are assumed to be appropriate, conservative values for use in the TEV tractive effort calculation.

R_w = Frictional resistance of locomotive = 20 [lb./ton]
a = rate of acceleration = 0.2 [mph/sec^2]
A = Acceleration force = 100 [lb./ton/mph/sec^2]
C = Resistance due to track curvature = 0.8 [lb./ton/degree]

Rationale: The preceding values were extracted from tables in *SME Mining Engineering Handbook* Reference 2.2.11, Section 14.

3.2.13 Lift Mechanism - Normal

Assumption: The normal lift mechanisms will be machine screw actuators with 100 [ton] capacity. The following properties are also assumed:

Weight with base = 845 [lb.]
Weight for each inch of rise = 7.4 [lb. per inch raise]
Required input torque = 6,900 [lb.-in]

Rationale: Consulting the Pow-R-Jac catalogue (or equivalent), the weight of the jack is 845 [lb.] with "0" travel and 7.4 [lb.] per inch of travel on a 6-inch diameter screw. The required input torque is 575 [lb.-ft], or 6,900 [lb. –in] with the optional ratio (Reference 2.2.13, Page MSJ-2). Confirmation of the lifting mechanism selection is determined later in the calculation.

3.2.14 Lift Mechanism - Off-Normal

Assumption: The off-normal lift mechanisms will be machine screw actuators with 150 [ton] capacity. The following properties are also assumed:

Weight with base = 1,335 [lb.]
Weight for each inch of rise = 13 [lb. per inch raise]
Required input torque = 15,552 [lb.-in]

Rationale: Consulting the Pow-R-Jac catalogue (or equivalent), the weight of the jack is 1,335 [lb.] with “0” travel. The 7-inch diameter screw is 13.0 [lb.] per inch of travel. The required input torque is 1,296 [lb.-ft] or 15,552 [lb.-in] with the optional ratio (Reference 2.2.13, page MSJ-19). Confirmation of the lifting mechanism selection is determined later in the calculation.

3.2.15 Electronics Cabinet Dimensions

Assumption: The TEV electronic cabinet will have the same profile as the shielded enclosure and will add an additional 48 [in] of length to the TEV.

Rationale: This should be adequate spacing for the electronics cabinets, and will provide a reasonable, conservative, bounding value.

3.2.16 TEV Wheel Size

Assumption: The TEV will be driven by 8 relieved wheels that are assumed to be 36 [in.] diameter, with an 8 [in.] width. The two wheels to support the bottom shield will have a 28 [in.] diameter and an 8 [in.] width. The weight of the wheel is 2,000 [lb.]

Rationale: Ultimately the size and number of wheels will be determined during detail design. These dimensions shown here provide a reasonable conservative value, for this preliminary design.

3.2.17 Miscellaneous Frame Component Weights

Assumption: An additional weight of 10,000 [lb.] is added to the chassis frame weight.

Rationale: This accounts for undeveloped component weights and additional structural members (for example, structural ribs, mounting pads, hinge blocks, etc.).

3.2.18 Electrical Enclosure Weight

Assumption: An additional weight of 5,000 [lb.] is added to the empty TEV weight.

Rationale: This accounts for the weight of the electrical enclosure and undeveloped component weights within (for example, actuators, programmable logic controllers, etc.).

4 METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation has been prepared in accordance with the *Calculations and Analyses* procedure (Reference 2.1.1). The *Basis of Design for the TAD Canister-Based Repository Design Concept* identifies the Transport and Emplacement Vehicle as Important to Safety and does not include any Systems, Structures, or Components that are Important to Waste Isolation, therefore the approved version is designated QA: QA (Reference 2.2.7, Section 14.1.2).

4.2 USE OF SOFTWARE

The following commercially available software has been used to generate the results of this calculation. All inputs, outputs, and equations are shown in their appropriate sections in the body of this document, and the results have been verified by hand calculation.

MathCAD

- Version: 13
- Operating Environment: Windows XP
- Computer Type: Dell personal computer

4.3 DESIGN METHODOLOGY

4.3.1 Using the largest waste package defined by *Waste Package Envelope Dimensions for Facilities and Handling* (Reference 2.2.10) and Pallet dimensions from *Emplacement Pallet Configuration* (Reference 2.2.4) the internal dimensions of the TEV shielded enclosure will be estimated.

4.3.2 The average shielding density is calculated, based on *Conceptual Shielding Study for Transport Emplacement Vehicle* (Reference 2.2.6).

4.3.2 The internal shielded enclosure dimensions and shielding thickness are added to develop the external shielded enclosure dimensions.

4.3.3 The shielded enclosure dimensions and average density are used to estimate the weight of the TEV Shielded enclosure.

4.3.4 Using the shielded enclosure weight, the heaviest waste package, and the heaviest pallet, the lifting mechanisms and lifting motors sizes are confirmed.

4.3.5 Using the shielded enclosure weight, the heaviest waste package, and heaviest pallet, the chassis beams, shield lift component weights, and the linear drive motor and gearbox weights, estimate linear motion drive motor and gearbox capacity.

4.3.6 Using previous sections, estimate the overall envelope for the TEV, doors open, and doors closed.

5 LIST OF ATTACHMENTS

	No. of Pages
Attachment 1: Conceptual Sketch to Indicate TEV Major Components	1
Attachment 2: One CD including MathCAD file: TEV MEE Calculation.xmcd	N/A

6 BODY OF CALCULATION

6.1 Internal Dimensions of TEV Shielding

6.1.1 Section Inputs

6.1.1.1 Longest Waste Package

The longest waste package identified is the "Naval Long" and "TAD" waste package, from *Waste Package Envelope Dimensions for Facilities and Handling* (Reference 2.2.10). The stated length is 233.32 inches. Due to the increase in length for the "South Texas" waste package discussed in Assumption 3.1.2, the longest waste package is 248 [in].

WP_Length = 248 [in]

6.1.1.2 Largest Waste Package Outer Diameter

The waste package with the largest upper and lower sleeve outside diameter from *Waste Package Envelope Dimensions for Facilities and Handling* (Reference 2.2.10) is the "5 DHLW/DOE", short or long, waste package. The stated diameter is 85.70 inches.

Upper_and_Lower_Sleeve_Outside_Diameter = 85.70 [in], See Figure 2.

6.1.1.3 Total Waste Package and Pallet Height

The total height of the waste package resting on an emplacement pallet, called WP_Total_Height_on_Pallet, is 92.49 inches (Reference 2.2.8).

WP_Total_Height_on_Pallet = 92.49 [in.], See Figure 2.

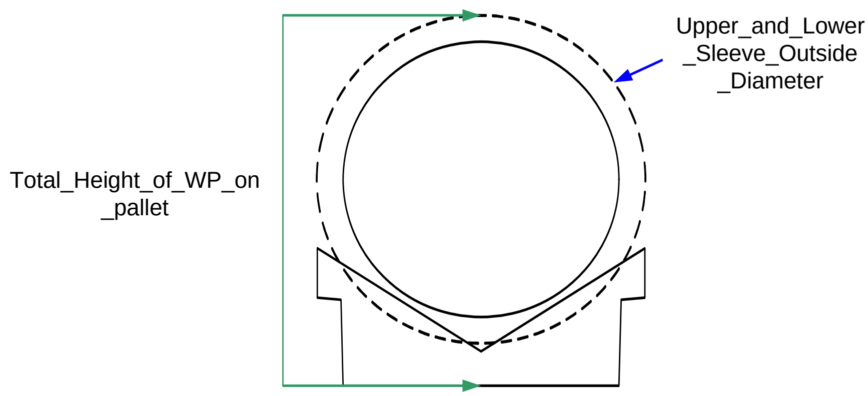


Figure 2: WP and Pallet Variable Definitions

6.1.1.4 Waste Package Clearance

To safely handle the waste package, a clearance assumption is used. See Assumption 3.2.1 for the basis.

WP_Clearance = 2 [in.]
Pallet_Clearance = 2 [in.]
Loading_and_Unloading_Clearance = 2 [in.]

6.1.2 Section Methodology

Identify waste package and pallet dimensions, and use geometry to develop the internal shield profile.

6.1.3 Calculation

6.1.3.1 Shielded Enclosure Internal Length

The shielded enclosure internal length, also called "Shielded_Enclosure_Internal_Length," is the distance between the shielded enclosure doors to the shielded enclosure rear wall. The shielded enclosure internal length is the length of the longest waste package, with two inches of clearance added onto both ends.

Where:
WP_Clearance = 2 [in], from Section 6.1.1.4
WP_Length = 248 [in], from Section 6.1.1.1

$$\begin{aligned} \text{Shielded\_Enclosure\_Internal\_Length} &= \text{WP\_Clearance} + \text{WP\_Length} + \text{WP\_Clearance} \\ &= 2 \cdot \text{in} + 248 \cdot \text{in} + 2 \cdot \text{in} \\ &= 252. \cdot \text{in} \end{aligned}$$

6.1.3.2 Shielded Enclosure Internal Width

The shielded enclosure internal width, also called "Shielded_Enclosure_Internal_Width," is the distance between the shielded enclosure side walls. The shielded enclosure internal width is the largest diameter waste package, with two inches of clearance added onto both sides.

Where:
WP_Clearance = 2 [in], from Section 6.1.1.4
Upper_and_Lower_Sleeve_Outside_Diameter = 85.70 [in], from Section 6.1.1.2

$$\begin{aligned} \text{Shielded\_Enclosure\_Internal\_Width} &= \text{WP\_Clearance} + \text{Upper\_and\_Lower\_Sleeve\_Outer\_Diameter} + \text{WP\_Clearance} \\ &= 2 \cdot \text{in} + 85.70 \cdot \text{in} + 2 \cdot \text{in} \\ &= 89.70 \cdot \text{in} \end{aligned}$$

6.1.3.3 Shielded Enclosure Internal Height

The shielded enclosure internal height, also called "Shielded_Enclosure_Internal_Height," is the distance between the shielded base plate to the shielded enclosure roof. To determine that distance, waste package clearance, pallet clearance, and loading/unloading clearance is added to the total waste package and pallet height.

Where:
WP_Total_Height_on_Pallet = 92.49 [in], Section 6.1.1.3
WP_Clearance = 2 [in.], from Section 6.1.1.4
Pallet_Clearance = 2 [in.], from Section 6.1.1.4
Loading_and_Unloading_Clearance = 2 [in.], from Section 6.1.1.4

$$\begin{aligned} \text{Shielded\_Enclosure\_Internal\_Height} &= \text{WP\_Clearance} + \text{WP\_Total\_Height\_on\_Pallet} + \text{Pallet\_Clearance} + \text{Loading\_Unloading\_Clearance} \\ &= 2 \cdot \text{in} + 92.49 \cdot \text{in} + 2 \cdot \text{in} + 2 \cdot \text{in} \\ &= 98.49 \cdot \text{in} \end{aligned}$$

6.2 External Dimensions of TEV Shielding
6.2.1 Section Inputs
6.2.1.1 Shielding Layer Thickness

The shielding profile is invoked with Assumption 3.1.1. The information in Table 1 was extracted from Section 2.1 of the *Conceptual Shielding Study for Transport Emplacement Vehicle* (Reference 2.2.6, Configuration B) and the *Dose Rate Calculation for Transport and Emplacement Vehicle* (Reference 2.2.14, Figure 2).

	Component	Material	Density (g/cm^3)	Density (lb/in^3)	Thickness (in.)
Layer_1	Inner Layer	SS316L	7.98	0.288	1.5
Layer_2	Gamma Shield	Depleted Uranium	18.95	0.685	1.5
Layer_3	Structural Steel	SS316L	7.98	0.288	0.5
Layer_4	Neutron Shield	NS-4-FR	1.68	0.061	6
Layer_5	Outer Layer	SS316L	7.98	0.288	0.5
				Total	10

Table 1: Shielding Profile

6.2.2 Section Methodology

Use the internal lengths determined in the previous section, and add the thickness of the shielding.

6.2.3 Calculation
6.2.3.1 Shielding External Length

The shielded enclosure external length, also called "Shielded_Enclosure_External_Length," is the shield thickness (front and rear) added to the shielded enclosure internal length.

Where:
Shield_Thickness = 10.0 [in], from Section 6.2.1.1.
Shielded_Enclosure_Internal_Length = 252 [in], from Section 6.1.3.1.

$$\begin{aligned}\text{Shielded\_Enclosure\_External\_Length} &= \text{Shield\_Thickness} + \text{Shielded\_Enclosure\_Internal\_Length} + \text{Shield\_Thickness} \\ &= 10\cdot in + 252.\cdot in + 10\cdot in \\ &= 272.\cdot in\end{aligned}$$

6.2.3.2 Shielding External Width

The shielding external width is defined as the total external width of the TEV shielding.

Where:
Shield_Thickness = 10.0 [in], from Section 6.2.1.1.
Shielded_Enclosure_Internal_Width = 89.70 [in], from Section 6.1.3.2.

$$\begin{aligned} \text{Shielded\_Enclosure\_External\_Width} &= \text{Shield\_Thickness} + \text{Shielded\_Enclosure\_Internal\_Width} + \text{Shield\_Thickness} \\ &= 10 \cdot \text{in} + 89.70 \cdot \text{in} + 10 \cdot \text{in} \\ &= 109.70 \cdot \text{in} \end{aligned}$$

6.2.3.3 Shielding External Height

The shielding external height is defined as the total external height of the TEV shielding, including clearance to remove the bottom shield.

Where:
Shield_Thickness = 10.0 [in], from Section 6.2.1.1.
Shielded_Enclosure_Internal_Height = 98.49 [in], from Section 6.1.3.3.

$$\begin{aligned} \text{Shielded\_Enclosure\_External\_Height} &= \text{Shield\_Thickness} + \text{Shielded\_Enclosure\_Internal\_Height} + \text{Shield\_Thickness} \\ &= 10 \cdot \text{in} + 98.49 \cdot \text{in} + 10 \cdot \text{in} \\ &= 118.49 \cdot \text{in} \end{aligned}$$

6.3 Weight of TEV shielding

6.3.1 Section Inputs

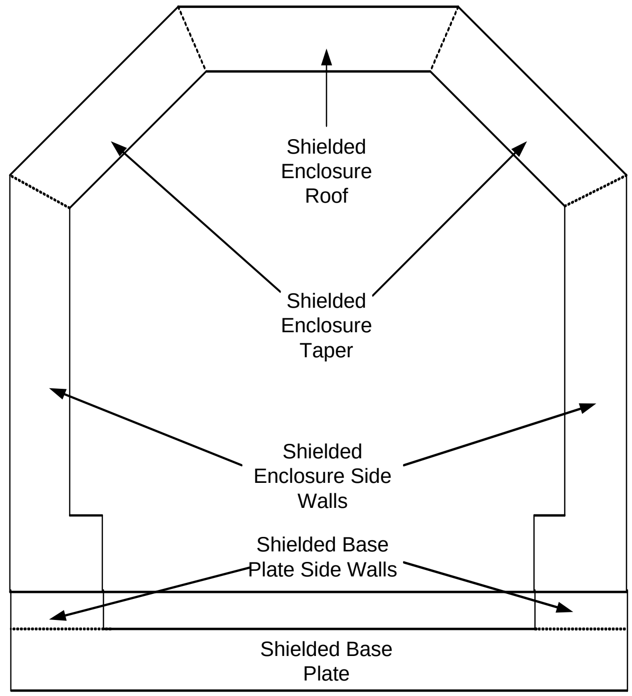
No new inputs.

6.3.2 Section Methodology

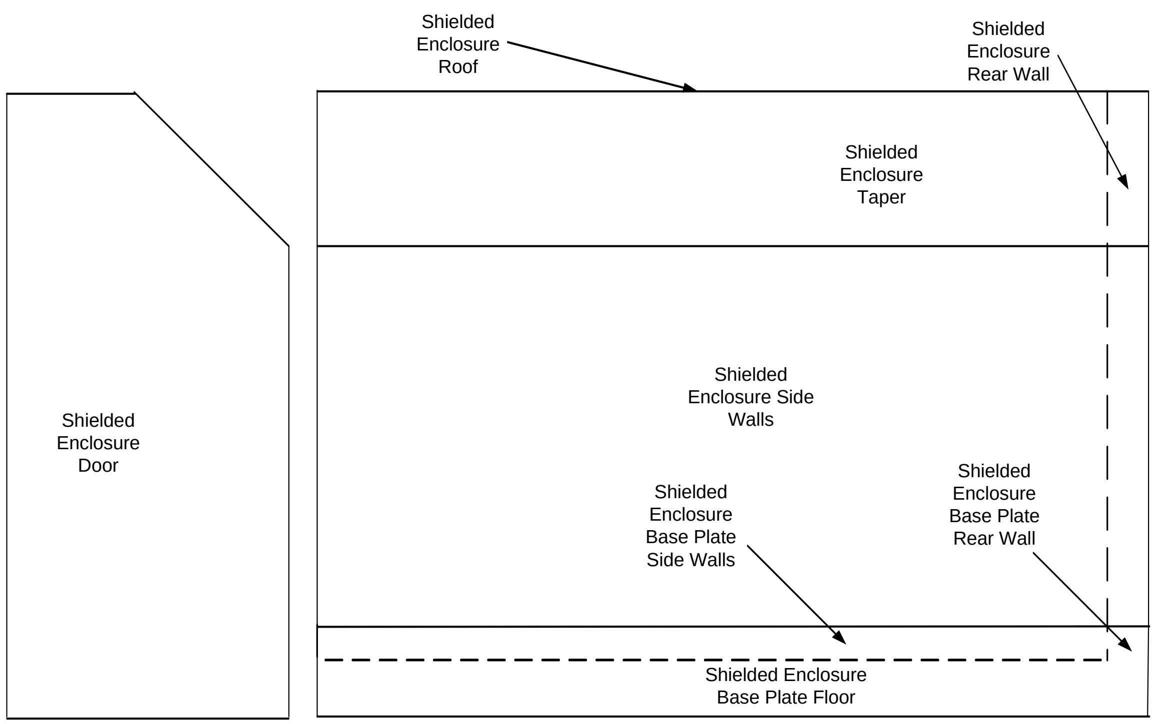
6.3.2.1 Shielded Enclosure Panel Identification Names

To determine the weight of the shielded enclosure, the complex structure must be separated into panels. The weight of these panels are separately calculated then added together. Since only a portion of the shielded enclosure is lifted by the shielded enclosure lifting mechanisms, the remaining panels (shielded base plate, shielded base plate side walls, and the shielded enclosure doors) are added to the overall weight to size the drive motors. Figure 3 identifies the TEV shielded enclosure panel names. The following is the process for calculating the total shielded enclosure lifting weight.

- The first shielded enclosure panels to calculate are the shielded enclosure roof and the shielded enclosure tapers. These panels are based on an octagon shape.
- The next panels to calculate are the shielded enclosure side walls.
- The remaining portion to be calculated is the shielded enclosure rear wall.
- The panels are added together for the total shielded enclosure lifting weight.



Section View



Side View

Figure 3: Shielded Enclosure Identified Panel Names

6.3.2.2 Average Density for the Shielded Enclosure

The average density calculated using the information presented in Section 6.2.1.1.

Where:

Layer_1_Thickness = 1.5 [in], Density_SS316 = 0.288 [lb./in.^{3}]
Layer_2_Thickness = 1.5 [in], Density_DU = 0.685 [lb./in.^{3}]
Layer_3_Thickness = 0.5 [in], Density_SS316 = 0.288 [lb./in.^{3}]
Layer_4_Thickness = 6.0 [in], Density_NS4FR = 0.061 [lb./in.^{3}]
Layer_5_Thickness = 0.5 [in], Density_SS316 = 0.288 [lb./in.^{3}]

$$\text{Average\_Density} := \frac{\begin{array}{l}\text{Layer\_1\_Thickness}\cdot\text{Density\_SS316}\ \ldots\\ +\text{Layer\_2\_Thickness}\cdot\text{Density\_DU}\ \ldots\\ +\text{Layer\_3\_Thickness}\cdot\text{Density\_SS316}\ \ldots\\ +\text{Layer\_4\_Thickness}\cdot\text{Density\_NS4FR}\ \ldots\\ +\text{Layer\_5\_Thickness}\cdot\text{Density\_SS316}\end{array}}{\text{Shield\_Thickness}}$$

$$= \frac{1.5\cdot in\cdot 0.288\cdot\frac{lb}{in^3} + 1.5\cdot in\cdot 0.685\cdot\frac{lb}{in^3} + 0.5\cdot in\cdot 0.288\cdot\frac{lb}{in^3} + 6\cdot in\cdot 0.061\cdot\frac{lb}{in^3} + 0.5\cdot in\cdot 0.288\cdot\frac{lb}{in^3}}{10\cdot in}$$

$$= .211\cdot\frac{lb}{in^3}$$

6.3.3 Calculate the Weight for the Upper Shielded Enclosure

6.3.3.1 Calculate the Weight for the Shielded Enclosure Roof and Shielded Enclosure Tapers

The profile of the shielded enclosure is similar to an octagon, where each panel is the side of an octagon centered around the largest waste package geometric center (as shown in Figure 4).

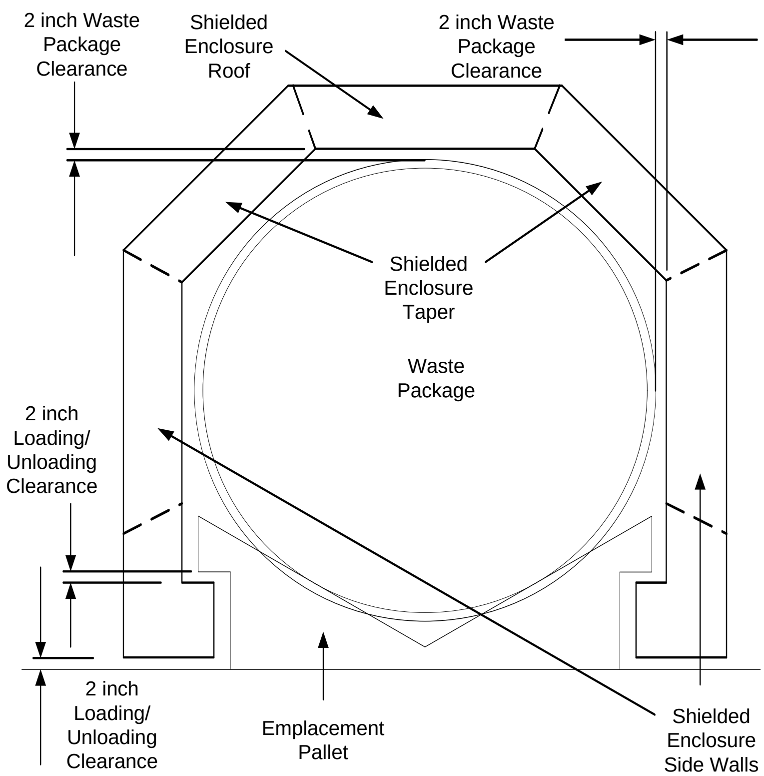


Figure 4: TEV Shielded Enclosure Identified Panel Names

Since the profile of the shielded enclosure is similar to an octagon for the shielded enclosure roof and shielded enclosure tapers, those panels are the same size. Therefore, only one panel needs to be calculated. Each side of the octagon, with the shielding thickness, is considered a trapezoid. The short length of the trapezoid is the shielded enclosure internal taper length; and the long length of the trapezoid is the shielded enclosure external taper length.

To determine length of the internal and external panel, an equation is used from the *Manual of Steel Construction*, Reference 2.2.1, Page 6-23, *Regular Polygon*.

$$R1 = \frac{a}{2\tan(\Phi)}$$

For use in this calculation, the equation is arranged in terms of "a."

$$a = 2 \cdot R1 \cdot \tan(\Phi)$$

Equation 1

Where:
R1 = the radius.
a = length of the octagon side
n = 8 for an octagon.
Φ = 180/n or 22.5 [deg]

6.3.3.1.1 Shielded Enclosure Internal Taper and Roof Length

To determine the Shielded Enclosure Internal Taper Length, Equation 1 is used. R1 is the shielded enclosure internal width (89.70 [in.]), from Section 6.1.3.2, divided by 2 to convert to radius.

Where:
Φ = 22.5 [deg], from Equation 1 explanation.

$$\begin{aligned}
\text{Shielding_Taper_Internal_Length} &= 2\cdot\frac{\text{Shielded_Enclosure_Internal_Width}}{2}\cdot\tan(\Phi) \\
&= 2\cdot\frac{89.70\cdot\text{in}}{2}\cdot\tan(22.5\cdot\text{deg}) \\
&= 37.16\cdot\text{in}
\end{aligned}$$

6.3.3.1.2 Shielded Enclosure External Taper and Roof Length

To determine the Shielded Enclosure External Taper and Roof Length, Equation 1 is used. R1 is the shielded enclosure external width (89.70 [in.]), from Section 6.1.3.2, divided by 2 to convert to radius. Additionally, 10 [in.] is added for the shielding thickness.

Where:
Shielded_Enclosure_Internal_Width = 89.70 [in.], from Section 6.1.3.2.
Shield_Thickness = 10 [in.], from Section 6.2.1.1.
Φ = 22.5 [deg], from Equation 1 explanation.

$$\begin{aligned}
\text{Shielding_Taper_External_Length} &= 2\cdot\left(\frac{\text{Shielded_Enclosure_Internal_Width}}{2} + \text{Shield_Thickness}\right)\cdot\tan(\Phi) \\
&= 2\cdot\left(\frac{89.70\cdot\text{in}}{2} + 10\cdot\text{in}\right)\cdot\tan(22.5\cdot\text{deg}) \\
&= 45.45\cdot\text{in}
\end{aligned}$$

6.3.3.1.3 Shielded Enclosure Taper and Roof Panel Area

Where:
Shielding_Thickness = 10 [in.], from Section 6.2.1.1
Shielding_Taper_Internal_Length = 37.16 [in.], from Section 6.3.3.1.1
Shielding_Taper_External_Length = 45.45 [in.], from Section 6.3.3.1.2

Therefore,

$$Shield\_Taper\_Area := \frac{Shield\_Thickness \cdot (Shielding\_Taper\_External\_Length + Shielding\_Taper\_Internal\_Length)}{2}$$

$$= \frac{10 \cdot in \cdot (45.45 \cdot in + 37.16 \cdot in)}{2}$$

$$= 413.1 \cdot in^2$$

6.3.3.1.4 Shielded Enclosure Taper and Roof Panel Weights

The weight for the shielded enclosure taper and roof panels are simply the multiplication of shield taper area, shielded enclosure internal length, and the average density.

Where:
Shield_Taper_Panel_Area = 413.1 [in.^{2}], from previous section.
Shielded_Enclosure_Internal_Length = 252 [in.], from Section 6.1.3.1.
Average_Density = 0.211 [lb./in.^{3}], from Section 6.3.2.2.

$$Shield\_Taper\_Panel\_Weight := Shield\_Taper\_Panel\_Area \cdot Shielded\_Enclosure\_Internal\_Length \cdot Average\_Density$$

$$= 413.1 \cdot in^2 \cdot 252. \cdot in \cdot .211 \cdot \frac{lb}{in^3}$$

$$= 21965. \cdot lb$$

6.3.3.2 Calculate the Weight for the Shielded Enclosure Side Walls

6.3.3.2.1 Shield Enclosure Side Wall Area

The shielded enclosure side walls are not the same area as the shielded enclosure roof and shielded enclosure tapers. The shielded enclosure side wall is a complex shape containing a rectangular and triangular section, as shown in Figure 5. The base is the shielding thickness, 10 [in.]. The triangle height is equal to (b-b1)/2. Furthermore, the triangular area is half the base multiplied by the height.

Where:
Base = Shield_Thickness = 10 [in.], from Section 6.2.1.1
b1 = Shielding_Taper_Internal_Length = 37.16 [in.], from Section 6.3.3.1.1
b = Shielding_Taper_External_Length = 45.45 [in.], from Section 6.3.3.1.2

$$Triangular\_Base := Shield\_Thickness$$

$$Triangular\_Height := \frac{Shielding\_Taper\_External\_Length - Shielding\_Taper\_Internal\_Length}{2}$$

$$= \frac{45.45 \cdot in - 37.16 \cdot in}{2}$$

$$= 4.15 \cdot in$$

$$Triangular\_Area := \frac{1}{2} \cdot Triangular\_Base \cdot Triangular\_Height$$

$$= \frac{1}{2} \cdot 10. \cdot in \cdot 4.15 \cdot in$$

$$= 20.75 \cdot in^2$$

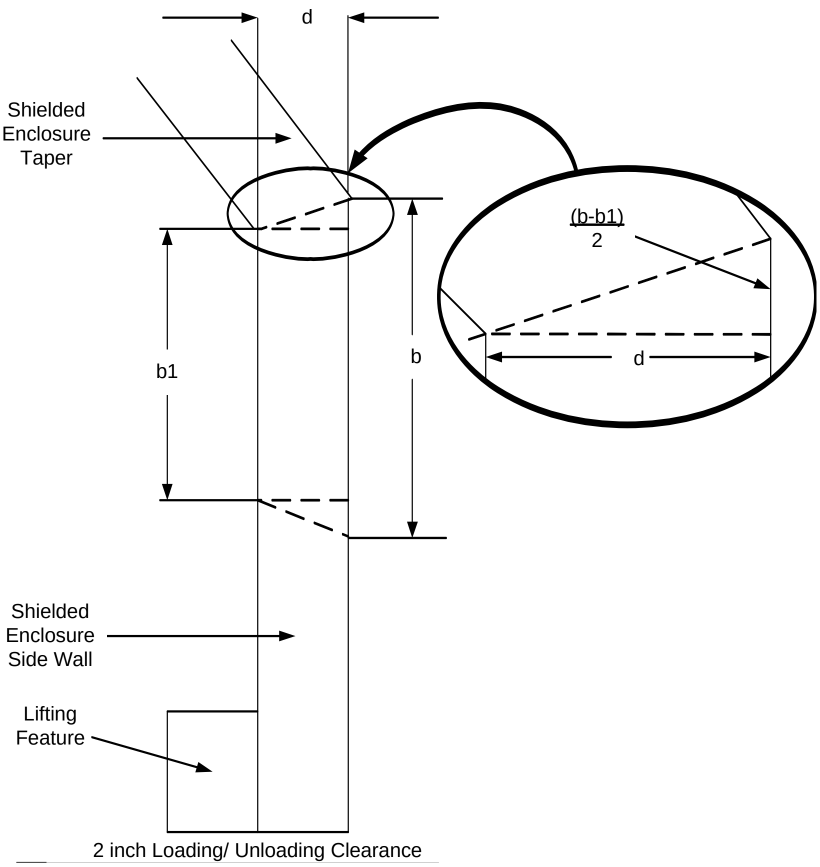


Figure 5: Shielded Enclosure Side Wall Detail and Section

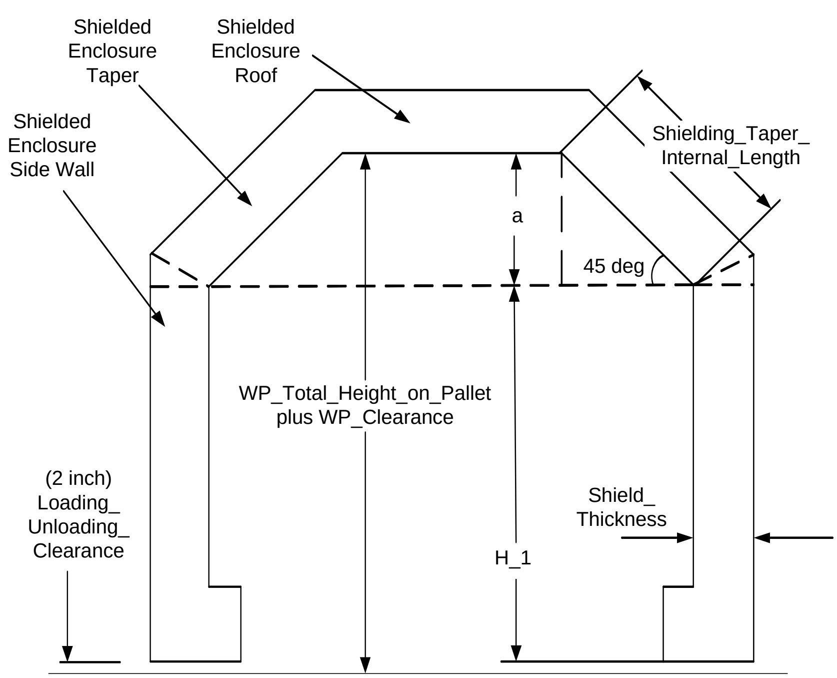


Figure 6: Shielded Enclosure Section

Using basic geometry in Figure 6, the height (H_1) of the rectangle is equal to subtracting the distance (a) and the 2 inch loading/unloading clearance (Loading_Unloading_Clearance) from the waste package total height on pallet (WP_Total_Height_on_Pallet) and waste package clearance (WP_Clearance). Using basic trigonometry:

$$a = c \cdot \sin(45deg)$$

Where:
c = Shielding_Taper_Internal_Length = 37.16 [in.], from Section 6.3.3.1.1

$$\begin{aligned} a &:= \text{Shielding\_Taper\_Internal\_Length} \cdot \sin(45deg) \\ &= 37.16 \cdot in \cdot \sin(45 \cdot deg) \\ &= 37.16 \cdot in \cdot 0.707 \\ &= 26.27 \cdot in \end{aligned}$$

Where:
WP_Total_Height_on_Pallet = 92.49 [in.], from Section 6.1.1.3
WP_Clearance = 2 [in.], from Section 6.1.1.4
Loading_Unloading_Clearance = 2 [in.], from Section 6.1.1.4

$$\begin{aligned} H\_1 &:= \text{WP\_Total\_Height\_on\_Pallet} + \text{WP\_Clearance} - (a + \text{Loading\_Unloading\_Clearance}) \\ &= 92.49 \cdot in + 2 \cdot in - (26.27 \cdot in + 2 \cdot in) \\ &= 66.22 \cdot in \end{aligned}$$

The area of the rectangle is equal to the shield thickness (Shield_Thickness) multiplied by the height (H_1).

Where:
Shield_Thickness = 10 [in.], from Section 6.2.1.1

$$\begin{aligned} \text{Rectangular\_Area} &:= \text{Shield\_Thickness} \cdot H\_1 \\ &= 10 \cdot in \cdot 66.22 \cdot in \\ &= 662.20 \cdot in^2 \end{aligned}$$

The total shielded enclosure side wall area is the triangular area (Triangular_Area) plus rectangular area (Rectangular_Area).

Where:
Triangular_Area = 20.75 [$in.^2$], from within this section
Rectangular_Area = 662.20 [$in.^2$], from within this section

$$\begin{aligned} \text{Total\_Side\_Wall\_Area} &:= \text{Triangular\_Area} + \text{Rectangular\_Area} \\ &= 20.75 \cdot in^2 + 662.20 \cdot in^2 \\ &= 682.95 \cdot in^2 \end{aligned}$$

6.3.3.2.2 Shielded Enclosure Side Wall Panel Weight

The weight for the shielded enclosure side wall panel is simply the multiplication of total side wall area, shielded enclosure internal length, and the average density.

Where:
Total_Side_Wall_Area = 682.95 [in.^{2}], from Section 6.3.3.2.1
Shielded_Enclosure_Internal_Length = 252 [in.], from Section 6.1.3.1
Average_Density = 0.211 [lb./in.^{3}], from Section 6.3.2.2

$$\text{Shield\_Side\_Wall\_Panel\_Weight} := \text{Total\_Side\_Wall\_Area} \cdot \text{Shielded\_Enclosure\_Internal\_Length} \cdot \text{Average\_Density}$$

$$= 682.95 \cdot \text{in}^2 \cdot 252. \cdot \text{in} \cdot .211 \cdot \frac{\text{lb}}{\text{in}^3}$$

$$= 36314. \cdot \text{lb}$$

6.3.3.3 Calculate the Weight for the Shielded Enclosure Rear Wall

6.3.3.3.1 Shield Enclosure Rear Wall Area

To calculate the total area for the shielded enclosure rear wall, the rear wall is separated into two simple shapes, a rectangle and a trapezoid. The area of a rectangle is the base (Shielded_Enclosure_External_Width) multiplied by the height (H_1 plus Triangular_Height), shown in Figure 7.

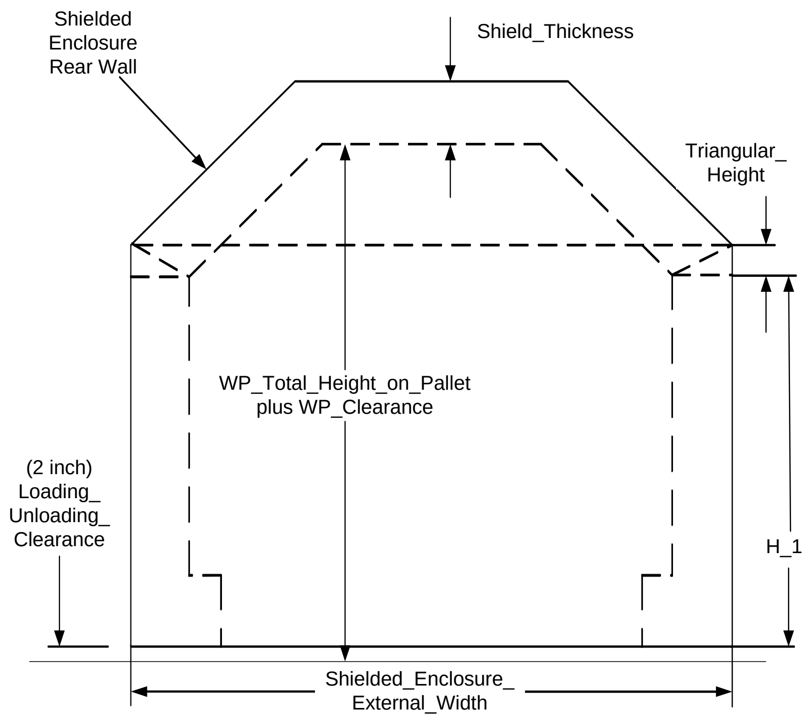


Figure 7: Shielded Enclosure Rear Wall

Where:
Shielded_Enclosure_External_Width = 109.70 [in.], from Section 6.2.3.2
H_1 = 66.22 [in.], from Section 6.3.3.2.1
Triangular_Height = 4.15 [in.], from Section 6.3.3.2.1

$$\begin{aligned}\text{Rear\_Wall\_Rectangular\_Area} &:= \text{Shielded\_Enclosure\_External\_Width}\cdot(\text{H\_1} + \text{Triangular\_Height})\\ &= 109.70\cdot\text{in}\cdot(66.22\cdot\text{in} + 4.15\cdot\text{in})\\ &= 7719.59\cdot\text{in}^2\end{aligned}$$

From Figure 7, the trapezoidal height is calculated by:

$$\begin{aligned}\text{Trapezoidal\_Height} &:= \begin{pmatrix}\text{WP\_Total\_Height\_on\_Pallet} \ldots\\ + \text{WP\_Clearance} \ldots\\ + \text{Shield\_Thickness}\end{pmatrix} - \begin{pmatrix}\text{Loading\_Unloading\_Clearance} \ldots\\ + \text{Triangular\_Height} \ldots\\ + \text{H\_1}\end{pmatrix}\\ &= 92.49\cdot\text{in} + 2\cdot\text{in} + 10\cdot\text{in} - (2\cdot\text{in} + 4.15\cdot\text{in} + 66.22\cdot\text{in})\\ &= 32.12\cdot\text{in}\end{aligned}$$

Where:

Trapezoidal_Height = 32.12 [in.], from within this section
Shielded_Enclosure_External_Width = 109.70 [in.], from Section 6.2.3.2
Shielding_Taper_External_Length = 45.45 [in.], from Section 6.3.3.1.2

$$\begin{aligned}\text{Trapezoidal\_Area} &:= \frac{\text{Trapezoidal\_Height}\cdot(\text{Shielded\_Enclosure\_External\_Width} + \text{Shielding\_Taper\_External\_Length})}{2}\\ &= \frac{32.12\cdot\text{in}\cdot(109.70\cdot\text{in} + 45.45\cdot\text{in})}{2}\\ &= 2491.71\cdot\text{in}^2\end{aligned}$$

Total Shield Enclosure Rear Wall Area is the sum of the trapezoidal area (Trapezoidal_Area) and rectangular area (Rear_Wall_Rectangular_Area).

Where:
Trapezoidal_Area = 2491.71 [in.^{2}], from within this section
Rear_Wall_Rectangular_Area = 7719.59 [in.^{2}], from within this section

$$\begin{aligned}\text{Total\_Rear\_Wall\_Area} &:= \text{Trapezoidal\_Area} + \text{Rear\_Wall\_Rectangular\_Area}\\ &= 2491.71\cdot\text{in}^2 + 7719.59\cdot\text{in}^2\\ &= 10211.30\cdot\text{in}^2\end{aligned}$$

6.3.3.3.2 Shielded Enclosure Rear Wall Panel Weight

The weight for the shielded enclosure rear wall panel is simply the multiplication of total rear wall area, shielding thickness, and the average density.

Where:

Total_Rear_Wall_Area = 10,211.30 [in.^{2}], from Section 6.3.3.3.1
Shield_Thickness = 10 [in.], from Section 6.2.1.1
Average_Density = 0.211 [lb./in.^{3}], from Section 6.3.2.2

$$\text{Shield\_Rear\_Wall\_Panel\_Weight} := \text{Total\_Rear\_Wall\_Area} \cdot \text{Shield\_Thickness} \cdot \text{Average\_Density}$$

$$= 10211.30 \cdot \text{in}^2 \cdot 10 \cdot \text{in} \cdot .211 \cdot \frac{\text{lb}}{\text{in}^3}$$

$$= 21546. \cdot \text{lb}$$

6.3.3.4 Upper Shielded Enclosure Total Weight

According to Figure 3, there are three shielded enclosure taper panels (including the roof), two shielded enclosure side panels, and a shielded enclosure rear panel. The weight of the upper shielded enclosure is simply a summation of these panel weights previously identified.

Where:
Shield_Taper_Panel_Weight = 21,965 [lb.], from Section 6.3.3.1.4.
Shield_Side Wall_Panel_Weight = 36,314[lb.], from Section 6.3.3.2.2.
Shield_Rear_Wall_Panel_Weight = 21,546 [lb.], from Section 6.3.3.3.2.

$$\begin{aligned}\text{Upper\_Shield\_Total\_Weight} &= 3 \cdot \text{Shield\_Taper\_Panel\_Weight} \ldots \\ &\quad + 2 \cdot \text{Shield\_Side\_Wall\_Panel\_Weight} \ldots \\ &\quad + \text{Shield\_Rear\_Wall\_Panel\_Weight} \\ &= 3 \cdot 21965. \cdot \text{lb} + 2 \cdot 36314. \cdot \text{lb} + 21546. \cdot \text{lb} \\ &= 160069. \cdot \text{lb} \\ &= 80.0 \cdot \text{ton}\end{aligned}$$

6.3.4 Shielded Enclosure Base Plate Weight

The shielded base plate is a composition of a several different panels: shielded base plate floor, shielded base plate side walls (2) and the shielded base plate rear wall (Figure 3).

6.3.4.1 Shielded Enclosure Base Plate Floor

6.3.4.1.1 Shielded Enclosure Base Plate Floor Area

The rectangular area of the shielded enclosure base plate floor is the base (Shielded_Enclosure_External_Width) multiplied by the height (Shield_Thickness).

Where:
Shielded_Enclosure_External_Width = 109.70 [in.], from Section 6.2.3.2.
Shield_Thickness = 10 [in.], from Section 6.2.1.1.

$$\begin{aligned}\text{Base\_Plate\_Floor\_Area} &:= \text{Shielded\_Enclosure\_External\_Width} \cdot \text{Shield\_Thickness} \\ &= 109.70 \cdot \text{in} \cdot 10 \cdot \text{in} \\ &= 1097.00 \cdot \text{in}^2\end{aligned}$$

6.3.4.1.2 Shielded Enclosure Base Plate Floor Weight

The weight of the shielded enclosure base plate floor is the area (Base_Plate_Floor_Area) multiplied by the length (Shielded_Enclosure_External_Length minus the Shield_Thickness [for the shielded enclosure doors]) and the density (Average_Density).

Where:
Base_Plate_Floor_Area = 1,097.00 [in.^{2}], from Section 6.3.4.1.1
Shielded_Enclosure_External_Length = 272 [in.], from Section 6.2.3.1.
Shield_Thickness = 10 [in.], from Section 6.2.1.1.
Average_Density = 0.211 [lb./in.^{3}], from Section 6.3.2.2.

$$\begin{aligned}\text{Base\_Plate\_Floor\_Weight} &:= \text{Base\_Plate\_Floor\_Area} \cdot (\text{Shielded\_Enclosure\_External\_Length} - \text{Shield\_Thickness}) \cdot \text{Average\_Density} \\ &= 1097.00 \cdot \text{in}^2 \cdot (272. \cdot \text{in} - 10 \cdot \text{in}) \cdot .211 \cdot \frac{\text{lb}}{\text{in}^3} \\ &= 60644. \cdot \text{lb}\end{aligned}$$

6.3.4.1.3 Shielded Enclosure Base Plate Side Wall Area

The height of the shielded enclosure base plate side wall is equal to the shielded enclosure internal height (Shielded_Enclosure_Internal_Height), minus the waste package total height (WP_Total_Height_on_Pallet), minus the waste package clearance (WP_Clearance), plus the loading / unloading clearance (Loading_Unloading_Clearance), as shown in Figure 8.

Where:
Shielded_Enclosure_Internal_Height = 98.49 [in.], from Section 6.1.3.3.
WP_Total_Height_on_Pallet = 92.49 [in.], from Section 6.1.1.3.
WP_Clearance = 2 [in.], from Section 6.1.1.4.
Loading_Unloading_Clearance = 2 [in.], from Section 6.1.1.4.

$$\begin{aligned}\text{Base\_Plate\_Side\_Wall\_Height} &:= \text{Shielded\_Enclosure\_Internal\_Height} - (\text{WP\_Total\_Height\_on\_Pallet} + \text{WP\_Clearance} - \text{Loading\_Unloading\_Clearance}) \\ &= 98.49 \cdot \text{in} - (92.49 \cdot \text{in} + 2 \cdot \text{in} - 2 \cdot \text{in}) \\ &= 6.00 \cdot \text{in}\end{aligned}$$

The rectangular area of the shielded enclosure base plate side wall is the base (Shield_Thickness) multiplied by the height (Base_Plate_Side_Wall_Height).

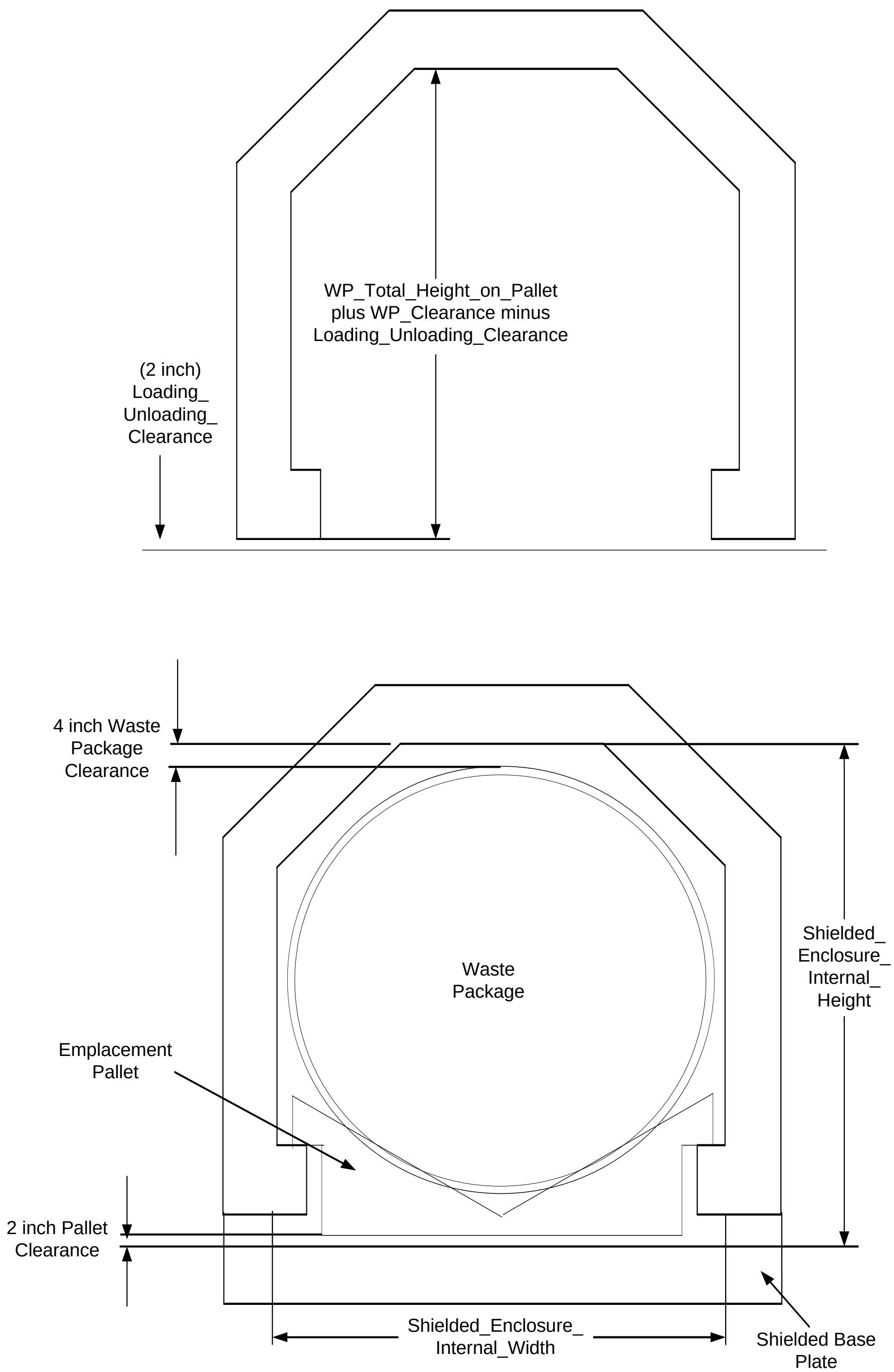


Figure 8: Loaded and Unloaded Shielded Enclosure

Where:
Shield_Thickness = 10 [in.], from Section 6.2.1.1.
Base_Plate_Side_Wall_Height = 6.00 [in.], from within this section.

$$\begin{aligned}\text{Base\_Plate\_Side\_Wall\_Area} &:= \text{Base\_Plate\_Side\_Wall\_Height} \cdot \text{Shield\_Thickness} \\ &= 6.00 \cdot \text{in} \cdot 10 \cdot \text{in} \\ &= 60.00 \cdot \text{in}^2\end{aligned}$$

6.3.4.1.4 Shielded Enclosure Base Plate Side Wall Weight

The weight of the shielded enclosure base plate floor is the area (Base_Plate_Floor_Area) multiplied by the length (Shielded_Enclosure_External_Length minus the Shield_Thickness [for the shielded enclosure doors]) and the density (Average_Density).

Where:
Base_Plate_Side_Wall_Area = 60.00 [in.^{2}], from Section 6.3.4.1.3
Shielded_Enclosure_External_Length = 272 [in.], from Section 6.2.3.1.
Shield_Thickness = 10 [in.], from Section 6.2.1.1.
Average_Density = 0.211 [lb./in.^{3}], from Section 6.3.2.2.

$$\begin{aligned}\text{Base\_Plate\_Side\_Wall\_Weight} &:= \text{Base\_Plate\_Side\_Wall\_Area} \cdot (\text{Shielded\_Enclosure\_External\_Length} - \text{Shield\_Thickness}) \cdot \text{Average\_Density} \\ &= 60.00 \cdot \text{in}^2 \cdot (272. \cdot \text{in} - 10 \cdot \text{in}) \cdot .211 \cdot \frac{\text{lb}}{\text{in}^3} \\ &= 3317. \cdot \text{lb}\end{aligned}$$

6.3.4.1.5 Shielded Enclosure Base Plate Rear Wall Area

The rectangular area of the shielded enclosure base plate rear wall is the base (Shielded_Enclosure_Internal_Width) multiplied by the height (Base_Plate_Rear_Wall_Height), as shown in Figure 8.

Where:
Shielded_Enclosure_Internal_Width = 89.70 [in.], from Section 6.1.3.2.
Base_Plate_Rear_Wall_Height = 6.00 [in.], from Section 6.3.4.1.3.

$$\begin{aligned}\text{Base\_Plate\_Rear\_Wall\_Area} &:= \text{Shielded\_Enclosure\_Internal\_Width} \cdot \text{Base\_Plate\_Side\_Wall\_Height} \\ &= 89.70 \cdot \text{in} \cdot 6.00 \cdot \text{in} \\ &= 538.20 \cdot \text{in}^2\end{aligned}$$

6.3.4.1.6 Shielded Enclosure Base Plate Rear Wall Weight

The weight of the shielded enclosure base plate floor is the area (Base_Plate_Rear_Wall_Area) multiplied by the length (Shield_Thickness) and the density (Average_Density).

Where:

Base_Plate_Rear_Wall_Area = 538.20 [in.^{2}], from Section 6.3.4.1.5
Shield_Thickness = 10 [in.], from Section 6.2.1.1.
Average_Density = 0.211 [lb./in.^{3}], from Section 6.3.2.2.

$$\begin{aligned}\text{Base\_Plate\_Rear\_Wall\_Weight} &:= \text{Base\_Plate\_Rear\_Wall\_Area}\cdot\text{Shield\_Thickness}\cdot\text{Average\_Density} \\ &= 538.20\cdot in^2\cdot 10\cdot in\cdot .211\cdot\frac{lb}{in^3} \\ &= 1136.\cdot lb\end{aligned}$$

6.3.4.2 Shielded Enclosure Base Plate Total Weight

The weight of the shielded enclosure base plate is simply a summation of base plate panel weights previously identified.

Where:
Base_Plate_Floor_Weight = 60,644 [lb.], from Section 6.3.4.1.2.
Base_Plate_Side_Wall_Weight = 3,317 [lb.], from Section 6.3.4.1.4.
Base_Plate_Rear_Wall_Weight = 1,136 [lb.], from Section 6.3.4.1.6.

$$\begin{aligned}\text{Base\_Plate\_Total\_Weight} &= \text{Base\_Plate\_Floor\_Weight} \ldots \\ &\quad + \text{Base\_Plate\_Side\_Wall\_Weight} \ldots \\ &\quad + \text{Base\_Plate\_Rear\_Wall\_Weight} \\ &= 60644.\cdot lb + 3317.\cdot lb + 1136.\cdot lb \\ &= 65097.\cdot lb \\ &= 32.5\cdot ton\end{aligned}$$

6.3.5 Calculate the Weight for the Shielded Enclosure Doors

6.3.5.1 Calculate the Weight for the Shielded Enclosure Doors

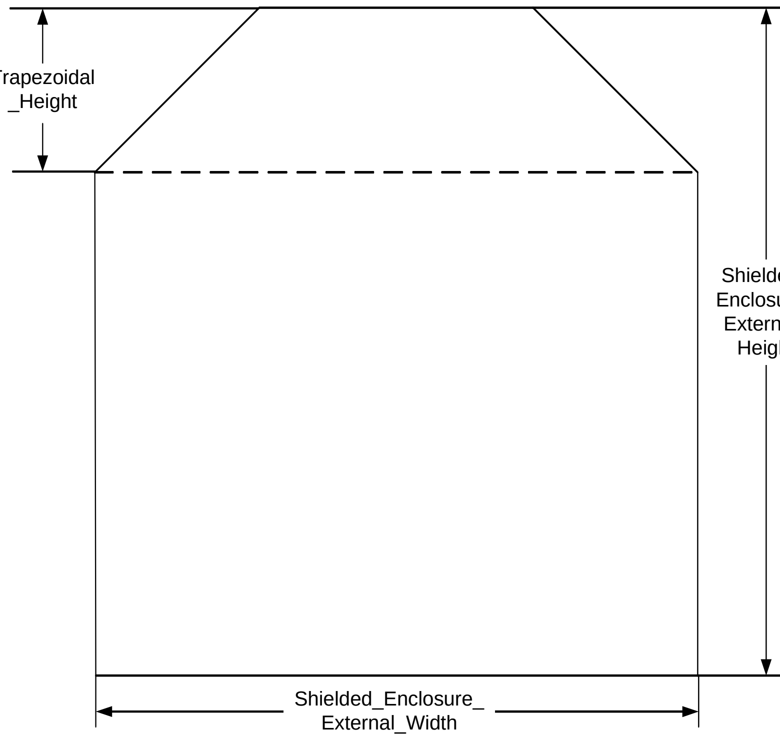


Figure 9: Shielded Enclosure Doors (Front View)

To calculate the total area for the shielded enclosure doors, the shielded enclosure doors are separated into two simple shapes, a trapezoid and a rectangle. The trapezoid was calculated previously in Section 6.3.3.3.1; the calculated trapezoidal area (Trapezoidal_Area) is 2491.71 [in.^{2}] and the trapezoidal height (Trapezoidal_Height) is 32.12 [in.].

The area of a rectangle is the base (Shielded_Enclosure_External_Width) multiplied by the height (Shielded_Enclosure_External_Height minus Trapezoidal_Height), shown in Figure 8

Where:
Trapezoidal_Height = 32.12 [in.], from Section 6.3.3.3.1.
Shielded_Enclosure_External_Width = 109.70 [in.], from Section 6.2.3.2.
Shielded_Enclosure_External_Height = 118.49 [in.], from Section 6.2.3.3.

$$\begin{aligned}\text{Door\_Rectangular\_Area} &:= \text{Shielded\_Enclosure\_External\_Width}\cdot(\text{Shielded\_Enclosure\_External\_Height} - \text{Trapezoidal\_Height})\\ &= 109.70\cdot\text{in}\cdot(118.49\cdot\text{in} - 32.12\cdot\text{in})\\ &= 9474.79\cdot\text{in}^2\end{aligned}$$

Where:
Trapezoidal_Area = 2491.71 [in.^{2}], from Section 6.3.3.3.1.
Door_Rectangular_Area = 9474.79 [in.^{2}], from within this section.

$$\begin{aligned}\text{Total\_Door\_Area} &:= \text{Trapezoidal\_Area} + \text{Door\_Rectangular\_Area}\\ &= 2491.71 \cdot in^2 + 9474.79 \cdot in^2\\ &= 11966.50 \cdot in^2\end{aligned}$$

6.3.5.2 Shielded Enclosure Doors Total Weight

The weight of the shielded enclosure doors are simply a multiplication of total door area (Total_Door_Area), the shield thickness (Shield_Thickness), and the average density (Average_Density).

Where:
Total_Door_Area = 11966.50 [in.^{2}], from Section 6.3.5.1.
Shield_Thickness = 10 [in.], from Section 6.2.1.1.
Average_Density = 0.211 [lb./in.^{3}], from Section 6.3.2.2.

$$\begin{aligned}\text{Total\_Door\_Weight} &:= \text{Total\_Door\_Area} \cdot \text{Shield\_Thickness} \cdot \text{Average\_Density}\\ &= 11966.50 \cdot in^2 \cdot 10 \cdot in \cdot .211 \cdot \frac{lb}{in^3}\\ &= 25249. \cdot lb\end{aligned}$$

6.4 TEV Main Chassis
6.4.1 Section Inputs
6.4.1.1 Heaviest Waste Package
The heaviest waste packages are the “Naval Long” and “TAD” waste packages, defined in *Waste Package Envelope Dimensions for Facilities and Handling* (Reference 2.2.10). The stated handling weight is 178,200 [lb.].

6.4.1.2 Largest Emplacement Pallet Weight

The largest waste package pallet defined in *Emplacement Pallet Configuration* (Reference 2.2.4) is the “Long” pallet. The stated handling weight is 5,500 [lb.].

6.4.2 Section Methodology

- Determine the largest load the TEV chassis will have to carry
- Identify worst case scenario
- Approximate the size of the beam

6.4.3 Calculation
6.4.3.1 Weight of Shielding, WP, and Pallet

Where:
Upper_Shield_Weight_Total = 160,069 [lb.], from Section 6.3.3.4.

Largest_WP_Weight = 178,200 [lb.], from Section 6.4.1.1.
Pallet_Weight = 5,500 [lb.], from Section 6.4.1.2.

$$\begin{aligned}\text{Weight\_to\_be\_Lifted} &= \text{Upper\_Shield\_Total\_Weight} \ldots \\ &\quad + \text{Largest\_WP\_Weight} \ldots \\ &\quad + \text{Pallet\_Weight} \\ &= 160069.\cdot\text{lb} + 178200\cdot\text{lb} + 5500\cdot\text{lb} \\ &= 343769.\cdot\text{lb}\end{aligned}$$

6.4.3.2 Lift Weight

Weight_to_be_Lifted = 343,769[lb.], from previous section.
Bounding_Factor = 1.1, from Assumption 3.2.2.

$$\begin{aligned}\text{Bounded\_Weight\_to\_Lift} &= \text{Weight\_to\_be\_Lifted}\cdot\text{Bounding\_Factor} \\ &= 343769.\cdot\text{lb}\cdot 1.1 \\ &= 378146.\cdot\text{lb}\end{aligned}$$

6.4.3.3 Chassis Beam Load

There are two chassis beams, one on each side of the TEV. The bounding lift weight is divided by two to analyze one beam.

Bounded_Weight_to_Lift = 378,146 [lb.], from previous section

$$\begin{aligned}\text{TEV\_Chassis\_Beam\_Load} &= \frac{\text{Bounded\_Weight\_to\_Lift}}{2} \\ &= \frac{378146.\cdot\text{lb}}{2} \\ &= 189073.\cdot\text{lb}\end{aligned}$$

6.4.3.4 TEV Chassis Span

The wheel blocks are directly below lift mechanisms, and are assumed as point loads (Assumption 3.2.6). The lift mechanisms are 80 [in] from both sides of center per Assumption 3.2.5. The chassis span is 160 [in].

6.4.3.5 Maximum Allowable Frame Deflection

From ASME NOG–1-2004, Section 4345, Reference 2.2.2, “The total vertical deflection of the girder shall not exceed 1/1000 of the span between legs… when the deflection is calculated as a simply supported beam.”

$$\Delta max = \frac{1}{1000} \cdot TEV\_Chassis\_Span$$
$$= \frac{1}{1000} \cdot 160 \cdot in$$
$$= .16 \cdot in$$

6.4.3.6 Chassis Moment of Inertia

From the *Manual of Steel Construction,* Reference 2.2.1, (Page 2-298, Section 7)

Using Assumption 3.2.4, the maximum deflection for a simply supported beam with a concentrated load at mid span.

Where:
P = concentrated load
l = length of beam between reaction points
E = Modulus of elasticity

I = Moment of inertia

$$\Delta max = \frac{P \cdot l^3}{48 \cdot E \cdot I}$$

For this calculation the moment of inertia is what the comparison will be based on so the equation is rearranged to show:

$$I = \frac{1}{48} \cdot P \cdot \frac{l^3}{\Delta max \cdot E}$$

Values are substituted where:
E = 29,000 [ksi] = 29,000,000 [psi], from Reference 2.2.1, Page 6-30.
Delta_Max = 0.16 [in], from Section 6.4.3.5.
TEV_Chassis_Span = 160 [in], from Section 6.4.3.4.
TEV_Chassis_Beam _Load = 189,073 [lb.], from Section 6.4.3.3

$$\text{Moment\_of\_Inertia\_Needed} = \frac{1}{48}\cdot\text{TEV\_Chassis\_Beam\_Load}\cdot\frac{\text{TEV\_Chassis\_Span}^3}{\Delta\text{max}\cdot E}$$

$$= \frac{1}{48}\cdot 189073.\cdot\text{lb}\cdot\frac{(160\cdot\text{in})^3}{.16\cdot\text{in}\cdot 29000000\cdot\text{psi}}$$

$$\text{Moment\_of\_Inertia\_Needed} = 3477\cdot\text{in}^4$$

6.4.3.7 Selected Beam Moment of Inertia

From Assumption 3.2.7, the TEV chassis beams will be a 20 [in] by 20 [in] box with a nominal wall thickness of 1.5 [in]. Using the following formula from *Mark's Standard Handbook for Mechanical Engineers*, Reference 2.2.3, Page 5-27, the moment of inertia for the desired beam can be calculated.

$$\text{I\_box} := \frac{H^4 - h^4}{12}$$

Where:
H = the outside dimension of the box profile, [20 in] from Assumption 3.2.7
h = the inside dimension of the box profile, 20 [in]-2*1.5 [in] = 17 [in], derived using Assumption 3.2.7

$$\text{I\_box} = \frac{H^4 - h^4}{12}$$

$$= \frac{(20\cdot\text{in})^4 - (17\cdot\text{in})^4}{12}$$

$$= 6373.\cdot\text{in}^4$$

Comparing the moment of inertia for the TEV chassis beam (6,373 [in^4]), to the moment of inertia needed to support the weight (3,477 [in^4]), we can see that the TEV chassis beam is capable of supporting the load in an off-normal scenario.

6.4.3.8 Chassis Frame Weight

The total length of the TEV chassis will be the external length of the shielding (Section 6.2.3.1), plus the additional length needed for the electronic cabinets (Assumption 3.2.15).

Area of Chassis Beam

The total cross section area for the TEV chassis beam is determined by:

Where:
H = 20 [in], from Assumption 3.2.7
h = 17 [in], derived using Assumption 3.2.7

$$
\begin{aligned}
A\_box &= H^2 - h^2 \\
&= (20 \cdot in)^2 - (17 \cdot in)^2 \\
&= 111. \cdot in^2
\end{aligned}
$$

Length of TEV chassis

The TEV chassis is longer than the "span" as discussed above. The chassis length is determined by adding the external length of the shielding and the additional length needed for the shielding cabinets.

Where:
Shielding_External_Length = 272 [in], from Section 6.2.3.1.
Electronics_Cabinet_Length = 48 [in], from Assumption 3.2.15.

$$
\begin{aligned}
Length\_of\_TEV\_Chassis &= Shielded\_Enclosure\_External\_Length + Electronics\_Cabinet\_Length \\
&= 272. \cdot in + 48 \cdot in \\
&= 320. \cdot in
\end{aligned}
$$

6.4.3.8.1 Weight of TEV Chassis Beam

The weight for the TEV main chassis beam is determined by:
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8.
Length_of_TEV_Chassis = 320 [in], previous section.
A_Box = 111 [in^2], previous section.

$$
\begin{aligned}
TEV\_Chassis\_Beam\_Weight &= (A\_box) \cdot (Length\_of\_TEV\_Chassis) \cdot (Density\_Steel) \\
&= 111. \cdot in^2 \cdot 320. \cdot in \cdot .284 \cdot \frac{lb}{in^3} \\
&= 10088. \cdot lb
\end{aligned}
$$

6.4.3.8.2 Weight of TEV Chassis Beam Ends

Based on Assumption 3.2.7, the beam area is 20 [in.] by 20 [in.] or 400 [in.^{2}].

The weight for the TEV chassis beam ends is determined by:
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8
Wall_Thickness = 1.5 [in], from Assumption 3.2.7
A_Beam_End = 400 [in^2], within this section

$$
\begin{aligned}
TEV\_Chassis\_Beam\_End\_Weight &= (A\_Beam\_End) \cdot (Wall\_Thickness) \cdot (Density\_Steel) \\
&= 400. \cdot in^2 \cdot 1.5 \cdot in \cdot .284 \cdot \frac{lb}{in^3} \\
&= 170. \cdot lb
\end{aligned}
$$

6.4.3.8.3 Weight of the Chassis Legs and Feet

TEV Chassis Leg Height

From the top of rail, the main chassis beam height is calculated by adding the wheel block height, the pivot base thickness, and the wheel block clearance.

Where:
Pivot_Base_Thickness = 2 [in.], from Assumption 3.2.6.
Wheel_Block_Height = 40 [in.], from Assumption 3.2.6.
Wheel_Block_Clearance = 2 [in.], from Assumption 3.2.6.

$$\text{Main\_Chassis\_Beam\_Height} := \text{Pivot\_Base\_Thickness} + \text{Wheel\_Block\_Height\_with\_Wheel} + \text{Wheel\_Block\_Clearance}$$
$$= 2\cdot in + 40\cdot in + 2\cdot in$$
$$= 44.\cdot in$$

The chassis leg height is the main chassis beam height minus the rail to feet clearance and feet thickness.

Where:
Main_Chassis_Beam_Height = 44 [in.], from within this section.
Rail_to_Feet_Clearance = 2 [in.], from Assumption 3.2.7.
Feet_Thickness = 1.5 [in.], from Assumption 3.2.7.

$$\text{Leg\_Height} := \text{Main\_Chassis\_Beam\_Height} - \text{Rail\_to\_Feet\_Clearance} - \text{Feet\_Thickness}$$
$$= 44.\cdot in - 2\cdot in - 1.5\cdot in$$
$$= 40.5\cdot in$$

Weight of TEV Chassis Beam Center Legs

The length of the chassis center leg is the wheel block pivot span minus wheel block length and 2-2 [in.] clearance.

Where:
Wheel_Block_Pivot_Span = 160 [in.], from Assumptions 3.2.5 and 3.2.6.
Wheel_Block_Length = 86 [in.], from Assumption 3.2.6.
Wheel_Block_Clearance = 2 [in.], from Assumption 3.2.6.

$$\text{Length\_of\_Chassis\_Center\_Leg} = \text{Wheel\_Block\_Pivot\_Span} - \text{Wheel\_Block\_Length} - \text{Wheel\_Block\_Clearance} - \text{Wheel\_Block\_Clearance}$$
$$= 160\cdot in - 86\cdot in - 2\cdot in - 2\cdot in$$
$$= 70.\cdot in$$

The weight for the chassis center leg side weight is determined by:
Length_of_Chassis_Center_Leg = 70 [in.], within this section.
Leg_Height = 40.5 [in.], from within this section.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8.

Wall_Thickness = 1.5 [in], from Assumption 3.2.7.

$$\begin{aligned}Chassis\_Center\_Leg\_Side\_Weight &= (Length\_of\_Chassis\_Center\_Leg \cdot Leg\_Height) \cdot (Wall\_Thickness) \cdot (Density\_Steel) \\ &= 70.\cdot in \cdot 40.5 \cdot in \cdot 1.5 \cdot in \cdot .284 \cdot \frac{lb}{in^3} \\ &= 1208.\cdot lb\end{aligned}$$

The weight for the chassis center leg end weight is determined by:
Chassis_Beam_Width = 20 [in.], from Assumption 3.2.7.
Leg_Height = 40.5 [in.], from within this section.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8.
Wall_Thickness = 1.5 [in], from Assumption 3.2.7.

$$\begin{aligned}Chassis\_Center\_Leg\_Ends\_Weight &= [(Chassis\_Beam\_Width - 2 \cdot Wall\_Thickness) \cdot Leg\_Height] \cdot (Wall\_Thickness) \cdot (Density\_Steel) \\ &= (20 \cdot in - 2 \cdot 1.5 \cdot in) \cdot 40.5 \cdot in \cdot 1.5 \cdot in \cdot .284 \cdot \frac{lb}{in^3} \\ &= 293.\cdot lb\end{aligned}$$

The weight for the chassis center leg end weight is 2 times the chassis center leg side weight and 2 times the chassis center leg ends weight
Where:
Chassis_Center_Leg_Side_Weight = 1,208 [lb.], within this section.
Chassis_Center_Leg_End_Weight = 293 [lb.], within this section.

$$\begin{aligned}Chassis\_Center\_Leg\_Weight &:= 2 \cdot Chassis\_Center\_Leg\_Side\_Weight + 2 \cdot Chassis\_Center\_Leg\_Ends\_Weight \\ &= 2 \cdot 1208.\cdot lb + 2 \cdot 293.\cdot lb \\ &= 3002.\cdot lb\end{aligned}$$

Weight of TEV Chassis Beam Center Feet

The chassis beam center feet are calculated by adding 6 inches to the chassis beam width and multiplying by the chassis center leg length, the feet thickness, and the density of steel.

$$\begin{aligned}Chassis\_Center\_Feet\_Weight &:= Length\_of\_Chassis\_Center\_Leg \cdot (Chassis\_Beam\_Width + 6 \cdot in) \cdot Feet\_Thickness \cdot Density\_Steel \\ &= 70.\cdot in \cdot (20 \cdot in + 6 \cdot in) \cdot 1.5 \cdot in \cdot .284 \cdot \frac{lb}{in^3} \\ &= 775.\cdot lb\end{aligned}$$

Weight of TEV Chassis Beam Front Legs

The length of the chassis front leg is the shielded enclosure external length minus two-wheel block lengths, the chassis center leg length, and the 2-2 [in.] clearances.

Where:
Length_of_Chassis_Center_Leg = 70 [in.], from within this section.
Shielded_Enclosure_External_Length = 272 [in.], from Section 6.2.3.1.
Wheel_Block_Length = 86 [in.], from Assumption 3.2.6.
Wheel_Block_Clearance = 2 [in.], from Assumption 3.2.6.

$$\text{Length\_of\_Chassis\_Front\_Leg} = \frac{\text{Shielded\_Enclosure\_External\_Length} - 2\cdot\text{Wheel\_Block\_Length} - 2\cdot\text{Wheel\_Block\_Clearance} - \text{Length\_of\_Chassis\_Center\_Leg}}{2}$$
$$= \frac{272.\cdot in - 2\cdot 86\cdot in - 2\cdot 2\cdot in - 70.\cdot in}{2}$$
$$= 13.00\cdot in$$

The weight for the chassis front leg side weight is determined by:
Length_of_Chassis_Front_Leg = 13.00 [in.], from within this section.
Leg_Height = 40.5 [in.], from within this section.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8.
Wall_Thickness = 1.5 [in], from Assumption 3.2.7.

$$\text{Chassis\_Front\_Leg\_Side\_Weight} = (\text{Length\_of\_Chassis\_Front\_Leg}\cdot\text{Leg\_Height})\cdot(\text{Wall\_Thickness})\cdot(\text{Density\_Steel})$$
$$= 13.00\cdot in\cdot 40.5\cdot in\cdot 1.5\cdot in\cdot .284\cdot\frac{lb}{in^3}$$
$$= 224.\cdot lb$$

The weight for the chassis front leg end weight is determined by:
Chassis_Beam_Width = 20 [in.], from Assumption 3.2.7.
Leg_Height = 40.5 [in.], from within this section.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8.
Wall_Thickness = 1.5 [in], from Assumption 3.2.7.

$$\text{Chassis\_Front\_Leg\_Ends\_Weight} = [(\text{Chassis\_Beam\_Width} - 2\cdot\text{Wall\_Thickness})\cdot\text{Leg\_Height}]\cdot(\text{Wall\_Thickness})\cdot(\text{Density\_Steel})$$
$$= (20\cdot in - 2\cdot 1.5\cdot in)\cdot 40.5\cdot in\cdot 1.5\cdot in\cdot .284\cdot\frac{lb}{in^3}$$
$$= 293.\cdot lb$$

The weight for the chassis front leg end weight is 2 times the chassis front leg side weight and 2 times the chassis front leg ends weight.
Where:
Chassis_Front_Leg_Side_Weight = 224 [lb.], within this section.
Chassis_Front_Leg_End_Weight = 293 [lb.], within this section.

$$\text{Chassis\_Front\_Leg\_Weight} := 2\cdot\text{Chassis\_Front\_Leg\_Side\_Weight} + 2\cdot\text{Chassis\_Front\_Leg\_Ends\_Weight}$$
$$= 2\cdot 224.\cdot lb + 2\cdot 293.\cdot lb$$
$$= 1034.\cdot lb$$

Weight of TEV Chassis Beam Front Feet

The chassis beam front feet are calculated by adding 6 inches to the chassis beam width and multiplying by the chassis front leg length, the feet thickness, and the density of steel.

$$\text{Chassis\_Front\_Feet\_Weight} := \text{Length\_of\_Chassis\_Front\_Leg} \cdot (\text{Chassis\_Beam\_Width} + 6 \cdot in) \cdot \text{Feet\_Thickness} \cdot \text{Density\_Steel}$$

$$= 13.00 \cdot in \cdot (20 \cdot in + 6 \cdot in) \cdot 1.5 \cdot in \cdot .284 \cdot \frac{lb}{in^3}$$

$$= 144. \cdot lb$$

Weight of TEV Chassis Beam Rear Legs

The length of the chassis rear leg is the chassis length minus two-wheel block lengths, the chassis center leg length, chassis front leg length, base plate wheel diameter, and the 3-2 [in.] clearances.

Where:
Length_of_TEV_Chassis = 320 [in.], from within this section.
Wheel_Block_Length = 86 [in.], from Assumption 3.2.6.
Wheel_Block_Clearance = 2 [in.], from Assumption 3.2.6.
Length_of_Chassis_Front_leg = 13.00 [in.], from within this section.
Base_Plate_Wheel_Diameter = 28 [in.], from Assumption 3.2.16.

$$\begin{aligned}\text{Length\_of\_Chassis\_Rear\_Leg} := {} & \text{Length\_of\_TEV\_Chassis} \ldots \\ & + -(2 \cdot \text{Wheel\_Block\_Length}) \ldots \\ & + -(3 \cdot \text{Wheel\_Block\_Clearance}) \ldots \\ & + -(\text{Length\_of\_Chassis\_Center\_Leg}) \ldots \\ & + -(\text{Length\_of\_Chassis\_Front\_Leg}) \ldots \\ & + -(\text{Base\_Plate\_Wheel\_Diameter})\end{aligned}$$

$$= 320. \cdot in + (-2 \cdot 86 \cdot in) + (-3 \cdot 2 \cdot in) + (-70. \cdot in) + (-13.00 \cdot in) + (-28 \cdot in)$$

$$= 31.00 \cdot in$$

The weight for the chassis rear leg side weight is determined by:
Length_of_Chassis_Rear_Leg = 31.00 [in.], from within this section.
Leg_Height = 40.5 [in.], from within this section.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8.
Wall_Thickness = 1.5 [in], from Assumption 3.2.7.

$$\text{Chassis\_Rear\_Leg\_Side\_Weight} = (\text{Length\_of\_Chassis\_Rear\_Leg} \cdot \text{Leg\_Height}) \cdot (\text{Wall\_Thickness}) \cdot (\text{Density\_Steel})$$

$$= 31.00 \cdot in \cdot 40.5 \cdot in \cdot 1.5 \cdot in \cdot .284 \cdot \frac{lb}{in^3}$$

$$= 535. \cdot lb$$

The weight for the chassis rear leg end weight is determined by:
Chassis_Beam_Width = 20 [in.], from Assumption 3.2.7.
Leg_Height = 40.5 [in.], from within this section.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8.
Wall_Thickness = 1.5 [in], from Assumption 3.2.7.

$$\text{Chassis\_Rear\_Leg\_Ends\_Weight} = [(\text{Chassis\_Beam\_Width} - 2\cdot\text{Wall\_Thickness})\cdot\text{Leg\_Height}]\cdot(\text{Wall\_Thickness})\cdot(\text{Density\_Steel})$$
$$= (20\cdot in - 2\cdot 1.5\cdot in)\cdot 40.5\cdot in\cdot 1.5\cdot in\cdot .284\cdot\frac{lb}{in^3}$$
$$= 293.\cdot lb$$

The weight for the chassis rear leg end weight is 2 times the chassis front leg side weight and 2 times the chassis front leg ends weight.
Where:
Chassis_Rear_Leg_Side_Weight = 535 [lb.], from within this section.
Chassis_Rear_Leg_End_Weight = 293 [lb.], from within this section.

$$\text{Chassis\_Rear\_Leg\_Weight} := 2\cdot\text{Chassis\_Rear\_Leg\_Side\_Weight} + 2\cdot\text{Chassis\_Rear\_Leg\_Ends\_Weight}$$
$$= 2\cdot 535.\cdot lb + 2\cdot 293.\cdot lb$$
$$= 1656.\cdot lb$$

Weight of TEV Chassis Beam Rear Feet

The chassis beam rear feet are calculated by adding 6 inches to the chassis beam width and multiplying by the chassis rear leg length, the feet thickness, and the density of steel.

$$\text{Chassis\_Rear\_Feet\_Weight} := \text{Length\_of\_Chassis\_Rear\_Leg}\cdot(\text{Chassis\_Beam\_Width} + 6\cdot in)\cdot\text{Feet\_Thickness}\cdot\text{Density\_Steel}$$
$$= 31.00\cdot in\cdot(20\cdot in + 6\cdot in)\cdot 1.5\cdot in\cdot .284\cdot\frac{lb}{in^3}$$
$$= 343.\cdot lb$$

6.4.3.8.4 Rear Lower Crossbeam

The rear lower crossbeam is an H-section that connects the two side frames. The 2 side plates are 25.5 [in.] in height and 2 [in.] thick. The center plate is 10 [in.] in width. The length of the beam is equal to the shielded enclosure external width plus 2-2 [in.] side frame clearances (Assumption 3.2.1).

Where:
Shielded_Enclosure_External_Width = 109.70 [in.], from Section 6.2.3.2.
Side_Frame_Clearance = 2 [in.], from Assumption 3.2.1.
H_Section_Side_Plate_Height = 25.5 [in.], from Assumption 3.2.7.
H_Section_Side_Plate_Width = 11 [in.], from Assumption 3.2.7.
H_Section_Plate_Thickness = 1.5 [in.], from Assumption 3.2.7.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8.

$$\text{Lower\_Cross\_Beam\_Width} := \text{Shielded\_Enclosure\_External\_Width} + 2\cdot\text{Side\_Frame\_Clearance}$$
$$= 109.70\cdot in + 2\cdot 2\cdot in$$
$$= 113.70\cdot in$$

$$\text{Lower\_Cross\_Beam\_Weight} := \begin{pmatrix} 2\cdot\text{H\_Section\_Side\_Plate\_Height}\cdot\text{H\_Section\_Plate\_Thickness}\ \ldots \\ +\text{H\_Section\_Center\_Plate\_Width}\cdot\text{H\_Section\_Plate\_Thickness} \end{pmatrix}\cdot\text{Lower\_Cross\_Beam\_Width}\cdot\text{Density\_Steel}$$
$$= (2\cdot 25.5\cdot in\cdot 1.5\cdot in + 11\cdot in\cdot 1.5\cdot in)\cdot 113.70\cdot in\cdot .284\cdot\frac{lb}{in^3}$$
$$= 3003.\cdot lb$$

6.4.3.8.5 Upper Crossbeams

The upper crossbeams are 10 [in.], box-sections that connect the two side frames. Thickness of the beam walls is 1 [in.] (Assumption 3.2.7).

$$
\begin{aligned}
A\_Upper\_Crossbeam &= H\_Crossbeam^2 - h\_Crossbeam^2 \\
&= (10\cdot in)^2 - (8\cdot in)^2 \\
&= 36.\cdot in^2
\end{aligned}
$$

The equivalent length of the beam is used to determine the weight of the upper crossbeam. Since the profile of the beam is similar to the profile of the shielded enclosure, the equivalent length is determined using a similar methodology presented in Section 6.3.3.1.2. However, the radius

Where:
Shielded_Enclosure_Internal_Width = 89.70 [in.], from Section 6.1.3.2.
Shield_Thickness = 10 [in.], from Section 6.2.1.1.
Side_Frame_Clearance = 2 [in.], from Assumption 3.2.1.
H_Crossbeam = 10 [in.], from Assumption 3.2.7.
Φ = 22.5 [deg], from Equation 1 explanation.

$$
\begin{aligned}
Upper\_Crossbeam\_Taper\_Length &= 2\cdot\left(\frac{Shielded\_Enclosure\_Internal\_Width}{2} + Shield\_Thickness + Side\_Frame\_Clearance + \frac{H\_Crossbeam}{2}\right)\cdot\tan(\Phi) \\
&= 2\cdot\left(\frac{89.70\cdot in}{2} + 10\cdot in + 2\cdot in + \frac{10\cdot in}{2}\right)\cdot\tan(22.5\cdot deg) \\
&= 51.25\cdot in
\end{aligned}
$$

Since the upper crossbeam is in three equal segments, the upper crossbeam taper length is multiplied by 3 to get the equivalent length.

$$
\begin{aligned}
Upper\_Crossbeam\_Equivalent\_Length &:= Upper\_Crossbeam\_Taper\_Length\cdot 3 \\
&= 51.25\cdot in\cdot 3 \\
&= 153.75\cdot in
\end{aligned}
$$

The upper crossbeam weight is determined by multiplying the area of the crossbeam, equivalent length, and the density of steel.

Where:
Upper_Crossbeam_Equivalent_Length = 153.75 [in.], from within this section.
A_Upper_Crossbeam = 36 [in.^{2}], from within this section.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb/in^3], from Reference 2.2.1, Page 6-8.

$$
\begin{aligned}
Upper\_Crossbeam\_Weight &:= Upper\_Crossbeam\_Equivalent\_Length\cdot A\_Upper\_Crossbeam\cdot Density\_Steel \\
&= 153.75\cdot in\cdot 36.\cdot in^2\cdot .284\cdot\frac{lb}{in^3} \\
&= 1572.\cdot lb
\end{aligned}
$$

6.4.3.8.6 Total Chassis Frame Weight

The total chassis frame weight is the summation of the components listed:

$$
\begin{aligned}
TEV\_Frame\_Weight := {} & 2 \cdot TEV\_Chassis\_Beam\_Weight \ldots \\
& + 4 \cdot TEV\_Chassis\_Beam\_End\_Weight \ldots \\
& + 2 \cdot Chassis\_Center\_Leg\_Weight \ldots \\
& + 2 \cdot Chassis\_Center\_Feet\_Weight \ldots \\
& + 2 \cdot Chassis\_Front\_Leg\_Weight \ldots \\
& + 2 \cdot Chassis\_Front\_Feet\_Weight \ldots \\
& + 2 \cdot Chassis\_Rear\_Leg\_Weight \ldots \\
& + 2 \cdot Chassis\_Rear\_Feet\_Weight \ldots \\
& + Lower\_Cross\_Beam\_Weight \ldots \\
& + 2 \cdot Upper\_Crossbeam\_Weight
\end{aligned}
$$

$$= 2 \cdot 10088. \cdot lb + 4 \cdot 170. \cdot lb + 2 \cdot 3002. \cdot lb + 2 \cdot 775. \cdot lb + 2 \cdot 1034. \cdot lb + 2 \cdot 144. \cdot lb + 2 \cdot 1656. \cdot lb + 2 \cdot 343. \cdot lb + 3003. \cdot lb + 2 \cdot 1572. \cdot lb$$

$$= 40911. \cdot lb$$

6.4.3.9 Miscellaneous Frame Component Weights

An additional 10,000 [lb.] is added to the total chassis frame weight to account for the miscellaneous frame components (Assumption 3.2.17).

$$
\begin{aligned}
Total\_TEV\_Frame\_Weight &= TEV\_Frame\_Weight + Miscellaneous\_Frame\_Components \\
&= 40911. \cdot lb + 10000 \cdot lb \\
&= 50911. \cdot lb
\end{aligned}
$$

$$Total\_TEV\_Frame\_Weight = 25.5\,ton$$

6.5 Lift mechanism, and drive motor size For TEV

6.5.1 Section Inputs

- Normal lift mechanism weight = 845 [lb.], from Assumption 3.2.13.
- Normal lift mechanism weight for each inch of rise = 7.4 [lb.], from Assumption 3.2.13.
- Off-normal lift mechanism weight = 1335 [lb.], from Assumption 3.2.14.
- Off-normal lift mechanism weight for each inch of rise = 13 [lb.], from Assumption 3.2.14.
- Normal lift gearbox and motor weight = 400 [lb.], from Assumption 3.2.10.
- Off-normal lift gearbox and motor weight = 600 [lb.], from Assumption 3.2.10.

6.5.2 Section Methodology

Verify selected lift features.

6.5.3 Calculation

6.5.3.1 Lift Travel

The lift travel is calculated where:
Shield_Thickness = 10 [in], from 6.2.1.1.
Rail_Height = 6 [in], from Assumption 3.2.8.
Pallet_Clearance = 2 [in], from Assumption 3.2.1.
Travel_Height = 2 [in], from Assumption 3.2.1.

Total_Lift_Travel = 2 [in] + 10 [in] + 6 [in] + 2 [in] = 20 [in]

6.5.3.2 Normal Lifting

In normal lifting, the TEV uses four lifting mechanisms to lift a total weight of 378,146 [lb.] (Section 6.4.3.2). To determine the required capacity of each lifting mechanism, the total weight is divided by 4. Therefore, each lifting mechanism must be capable of lifting 94,536 [lb.] or 47.3 [ton]. For the purpose of this calculation a 100 [ton] machine screw actuator is selected. Details for a typical commercially available 100 [ton] machine screw actuator can be found in Assumption 3.2.13.

6.5.3.3 Off-normal Lifting

In off-normal lifting, the TEV uses two lifting mechanisms to lift a total weight of 378,146 [lb.] (Section 6.4.3.2). To determine the required capacity of each lifting mechanism, the total weight is divided by 2. Therefore, each lifting mechanism must be capable of lifting 189,073 [lb.] or 94.5 [ton]. For the purpose of this calculation a 150 [ton] machine screw actuator is selected. Details for a typical commercially available 150 [ton] machine screw actuator can be found in Assumption 3.2.14.

6.5.3.4 Lift System Weight

The normal lift mechanism weight with base is 845 [lb.], from Assumption 3.2.13. The total lift height needed is 20 [in], from Section 6.5.3.1. According to Assumption 3.2.13, 7.4 [lb. per inch] is added for each inch of rise. The total weight for a normal lift mechanism is:

$$\text{Normal\_Lift\_Mechanism\_Weight} = 845\text{lb} + 20\cdot\text{in}\cdot 7.4\,\frac{\text{lb}}{\text{in}}$$

$$\text{Normal\_Lift\_Mechanism\_Weight} = 993\ \text{lb}$$

Rounded up to 1,000 [lb.].

The off-normal lift mechanism weight with base is 1,335 [lb.], from Assumption 3.2.14. The total lift height needed is 20 [in], from Section 6.5.3.1. With 13 [lb. per inch], Assumption 3.2.14, needed for each inch of rise. The total weight for an off-normal lift mechanism is:

$$\text{OffNormal\_Lift\_Mechanism\_Weight} = 1335\text{lb} + 20\cdot\text{in}\cdot 13\,\frac{\text{lb}}{\text{in}}$$

$$\text{OffNormal\_Lift\_Mechanism\_Weight} = 1595\ \text{lb}$$

Rounded up to 1,600 [lb.].

The normal lift gearbox and motor weight is 400 [lb.]. The off-normal lift gearbox and motor weight is 600 [lb.], as discussed in Assumption 3.2.10. The total weight for the lift system is therefore:

$$\begin{aligned}\text{Lift\_System\_Weight} &= (4)\text{Normal\_Lift\_Motor\_Weight} + (2)\text{OffNormal\_Lift\_Motor\_Weight}\ \ldots\\ &\quad + (4)\cdot\text{Normal\_Lift\_Mechanism\_Weight}\ \ldots\\ &\quad + (2)\text{OffNormal\_Lift\_Mechanism\_Weight}\\ &= 4\cdot 400\cdot\text{lb} + 2\cdot 600\cdot\text{lb} + 4\cdot 1000\cdot\text{lb} + 2\cdot 1600\cdot\text{lb}\\ &= 10000.\cdot\text{lb}\end{aligned}$$

6.6 Total Weight of TEV

6.6.1 Section Inputs

No new inputs.

6.6.2 Section Methodology

Add significant weights.

6.6.3 Calculation

6.6.3.1 Drive system weight

Wheel Block Structure Weight

The wheel block side weight is determined by multiplying the wheel block length, the wheel block height, the wheel block thickness, and the density of steel.

Where:
Wheel_Block_Length = 86 [in.], from Assumption 3.2.6.
Wheel_Block_Height = 36 [in.], from Assumption 3.2.6.
Wheel_Block_Thickness = 2 [in.], from Assumption 3.2.6.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb./in.^{3}], from Reference 2.2.1, Page 6-8.

$$\begin{aligned}\text{Wheel\_Block\_Side\_Weight} &:= \text{Wheel\_Block\_Length}\cdot\text{Wheel\_Block\_Height}\cdot\text{Wheel\_Block\_Thickness}\cdot\text{Density\_Steel}\\ &= 86\cdot in\cdot 36\cdot in\cdot 2\cdot in\cdot .284\cdot\frac{lb}{in^3}\\ &= 1759.\cdot lb\end{aligned}$$

The wheel block end weight is determined by multiplying the wheel block width (minus 2 times the wheel block thickness), the wheel block height, the wheel block thickness, and the density of steel.

Where:
Wheel_Block_Width = 14 [in.], from Assumption 3.2.6.
Wheel_Block_Height = 36 [in.], from Assumption 3.2.6.
Wheel_Block_Thickness = 2 [in.], from Assumption 3.2.6.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb./in.^{3}], from Reference 2.2.1, Page 6-8.

$$\begin{aligned}\text{Wheel\_Block\_End\_Weight} &:= (\text{Wheel\_Block\_Width} - 2\cdot\text{Wheel\_Block\_Thickness})\cdot\text{Wheel\_Block\_Height}\cdot\text{Wheel\_Block\_Thickness}\cdot\text{Density\_Steel}\\ &= (14\cdot in - 2\cdot 2\cdot in)\cdot 36\cdot in\cdot 2\cdot in\cdot .284\cdot\frac{lb}{in^3}\\ &= 204.\cdot lb\end{aligned}$$

The weight for a wheel block structure is determined adding 2 times the wheel block side weight, 2 times the wheel block end weight, and the wheel block top weight.

Where:
Wheel_Block_Side_Weight = 1,759 [lb.], from within this section.
Wheel_Block_End_Weight = 204 [lb.], from within this section.

$$
\begin{aligned}
\text{Wheel\_Block\_Structure\_Weight} &:= 2\cdot\text{Wheel\_Block\_Side\_Weight} + 2\cdot\text{Wheel\_Block\_End\_Weight} \\
&= 2\cdot 1759.\cdot\text{lb} + 2\cdot 204.\cdot\text{lb} \\
&= 3926.\cdot\text{lb}
\end{aligned}
$$

Wheel Block Weight

Wheel_Block_Structure_Weight = 3,926 [lb.], from within this section.
Wheel_Weight = 2,000 [lb.], from Assumption 3.2.16.
Drive_System = 1,000 [lb.], from Assumption 3.2.11
Number_of_Drive_Wheels = 2, from Assumption 3.2.16

$$
\begin{aligned}
\text{Wheel\_Block\_Weight} &= (2)(\text{Wheel\_Weight} + \text{Drive\_System}) + \text{Wheel\_Block\_Structure\_Weight} \\
&= 2\cdot(2000\cdot\text{lb} + 1000\cdot\text{lb}) + 3926.\cdot\text{lb} \\
&= 9926.\cdot\text{lb}
\end{aligned}
$$

Wheel Block Pivot Fabrications Weight

The wheel block pivot top weight is determined by multiplying the wheel block pivot length, the chassis beam width, the wheel block pivot thickness, and the density of steel.

Where:
Wheel_Block_Pivot_Length = 88 [in.], from Assumption 3.2.6.
Chassis_Beam_Width = 20 [in.], from Section 6.4.3.7.
Wheel_Block_Pivot_Thickness = 2 [in.], from Assumption 3.2.6.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb./in.^{3}], from Reference 2.2.1, Page 6-8.

$$
\begin{aligned}
\text{Wheel\_Block\_Pivot\_Top\_Weight} &:= \text{Wheel\_Block\_Pivot\_Length}\cdot\text{Chassis\_Beam\_Width}\cdot\text{Wheel\_Block\_Pivot\_Thickness}\cdot\text{Density\_Steel} \\
&= 88\cdot\text{in}\cdot 20\cdot\text{in}\cdot 2\cdot\text{in}\cdot .284\cdot\frac{\text{lb}}{\text{in}^3} \\
&= 999.7\cdot\text{lb}
\end{aligned}
$$

The wheel block pivot side weight is determined by multiplying one half the wheel block pivot length, the wheel block pivot height, the wheel block pivot thickness, and the density of steel.

Where:
Wheel_Block_Pivot_Length = 88 [in.], from Assumption 3.2.6.
Wheel_Block_Pivot_Height = 37 [in.], from Assumption 3.2.6.
Wheel_Block_Pivot_Thickness = 2 [in.], from Assumption 3.2.6.
Density_Steel = 490 [lb./ft^3] or 0.284 [lb./in.^{3}], from Reference 2.2.1, Page 6-8.

$$
\begin{aligned}
\text{Wheel\_Block\_Pivot\_Side\_Weight} &:= \left(\frac{1}{2}\cdot\text{Wheel\_Block\_Pivot\_Length}\cdot\text{Wheel\_Block\_Pivot\_Height}\right)\cdot\text{Wheel\_Block\_Pivot\_Thickness}\cdot\text{Density\_Steel} \\
&= \frac{1}{2}\cdot 88\cdot\text{in}\cdot 37\cdot\text{in}\cdot 2\cdot\text{in}\cdot .284\cdot\frac{\text{lb}}{\text{in}^3} \\
&= 925.\cdot\text{lb}
\end{aligned}
$$

The weight for a wheel block pivot fabrication is determined adding 2 times the wheel block pivot side weight and the wheel block pivot top weight.

Where:
Wheel_Block_Pivot_Top_Weight = 999.7 [lb.], from within this section.

Wheel_Block_Pivot_Side_Weight = 925 [lb.], from within this section.

$$\begin{aligned}\text{Wheel\_Block\_Pivot\_Weight} &= 2\cdot\text{Wheel\_Block\_Pivot\_Side\_Weight} + \text{Wheel\_Block\_Pivot\_Top\_Weight} \\ &= 2\cdot 925.\cdot\text{lb} + 999.7\cdot\text{lb} \\ &= 2850.\cdot\text{lb}\end{aligned}$$

6.6.3.2 Total Shield Weight

The total shield weight (Shield_Weight_Total) is simply the summation of the upper shield (Upper_Shield_Weight), shielded base plate (Base_Plate_Total_Weight), and the shielded enclosure doors weight (Total_Door_Weight).

Where:
Upper_Shield_Weight = 160,069 [lb.], from Section 6.3.3.4.
Base_Plate_Total_Weight = 65,097 [lb.], from Section 6.3.4.2.
Total_Door_Weight = 25,249 [lb.], from Section 6.3.5.2.

$$\begin{aligned}\text{Shield\_Weight\_Total} &:= \text{Upper\_Shield\_Total\_Weight} \ldots \\ &\quad + \text{Base\_Plate\_Total\_Weight} \ldots \\ &\quad + \text{Total\_Door\_Weight} \\ &= 160069.\cdot\text{lb} + 65097.\cdot\text{lb} + 25249.\cdot\text{lb} \\ &= 250415.\cdot\text{lb}\end{aligned}$$

$$\text{Shield\_Weight\_Total} = 125.2\,\text{ton}$$

6.6.3.3 Empty TEV Weight

Where:
Shield_Weight_Total = 250,415 [lb.], from previous section.
TEV_Frame_Weight = 50,911 [lb.], from Section 6.4.3.9.
Lift_System_Weight = 10,000 [lb.], from Section, 6.5.3.4.
Wheel_Block_Weight = 9,926 [lb.], from Section 6.6.3.1.
Wheel_Block_Pivot_Weight = 2,850 [lb.], from Section 6.6.3.1.
Electrical_Enclosure_Weight = 5,000 [lb.], from Assumption 3.2.18.

$$\begin{aligned}\text{TEV\_Empty\_Weight} &= \text{Shield\_Weight\_Total} \ldots \\ &\quad + \text{Total\_TEV\_Frame\_Weight} \ldots \\ &\quad + \text{Lift\_System\_Weight} \ldots \\ &\quad + 4\cdot\text{Wheel\_Block\_Weight} \ldots \\ &\quad + 4\cdot\text{Wheel\_Block\_Pivot\_Weight} \ldots \\ &\quad + \text{Electrical\_Enclosure\_Weight} \\ &= 250415.\cdot\text{lb} + 50911.\cdot\text{lb} + 10000.\cdot\text{lb} + 4\cdot 9926.\cdot\text{lb} + 4\cdot 2850.\cdot\text{lb} + 5000\cdot\text{lb} \\ &= 367430.\cdot\text{lb}\end{aligned}$$

$$\text{TEV\_Empty\_Weight} = 183.7\,\text{ton}$$

6.6.3.4 Loaded TEV Weight

Where:
TEV_Empty_Weight = 367,430 [lb.], from Section 6.6.3.3.
Largest_WP_Weight = 178,200 [lb.], from Section,6.4.1.1.

Pallet_Weight = 5,500 [lb.], from Section, 6.4.1.2.

$$\begin{aligned} \text{TEV\_Loaded\_Weight} &= \text{TEV\_Empty\_Weight} \ldots \\ &\quad + \text{Largest\_WP\_Weight} \ldots \\ &\quad + \text{Pallet\_Weight} \\ &= 367430.\cdot\text{lb} + 178200\cdot\text{lb} + 5500\cdot\text{lb} \\ &= 551130.\cdot\text{lb} \end{aligned}$$

$$\text{TEV\_Loaded\_Weight} = 275.6\,\text{ton}$$

6.6.3.5 Bounding TEV Loaded Weight

TEV_Loaded_Weight = 551,130 [lb.], from previous section.
Rounded up to 300 [tons].

6.7 TEV Horizontal Drive System

6.7.1 Section Inputs

No new inputs.

6.7.2 Tractive Effort

From the *SME Mining Engineering Handbook*, the tractive effort required to haul a train is the sum of the various tractive resistances of both the locomotive and the load (Reference 2.2.11, Page 14-11, Equation (1)). Since the TEV is only one vehicle, some of the terms in the equation drop out. The Tractive Effort is calculated using Equation 2.

$$TE = W \cdot R_w + L \cdot R + T \cdot g \cdot G + T \cdot a \cdot A + T \cdot c \cdot C$$

Equation 2

Where:
TE = The tractive effort of the locomotive [lb.]
W = Locomotive weight [ton]
T = Total train weight, for this calculation. T = W
R_w = Frictional resistance of locomotive [lb./ton]
L = Trailing load, zero for this calculation [ton]
R = Frictional Resistance of coupled train, zero for this calculation [lb./ton]
g = percent grade [%grade]
G =Grade resistance [lb./ton/%grade]
a = rate of acceleration [mph/sec^2]
A = Acceleration force [lb./ton/mph/sec^2]
c = degrees of track curvature [degree]
C = Resistance due to track curvature [lb./ton]

Three scenarios need to be evaluated, tractive effort on a grade, tractive effort in a curve (200-ft radius) and tractive effort on a grade in a curve (1000-ft radius) (Reference 2.2.5, Figure 3). Whichever scenario produces the highest tractive effort, is used to develop the horsepower.

Tractive effort on a grade

To calculate the tractive effort up a grade, the curvature and trailing load terms in Equation 2 are reduced to 0.

Where:
W = 300 [ton], from Section 6.6.3.5.
R_w = 20 [lb./ton], from Assumption 3.2.12.
T= W
g = 2.5 [%grade], from Reference 2.2.7, Section 9.9.2.2.4.
G = 20 [lb./ton/%grade], from Reference 2.2.11, Section 14.
a = 0.2 [mph/sec^2], from Assumption 3.2.12.
A = 100 [lb./ton/mph/sec^2], from Assumption 3.2.12.

$$TE\_grade = W \cdot R_w + T \cdot g \cdot G + T \cdot a \cdot A$$

$$= 300. \cdot ton \cdot 20 \cdot \frac{lb}{ton} + 300. \cdot ton \cdot 2.5 \cdot \%grade \cdot 20 \cdot \frac{lb}{ton \cdot \%grade} + 300. \cdot ton \cdot .2 \cdot \frac{mph}{sec^2} \cdot 100 \cdot \frac{\frac{lb}{ton}}{\frac{mph}{sec^2}}$$

$$= 27000. \cdot lb$$

Tractive effort in curve

The TEV must negotiate a 200-ft radius curve (Reference 2.2.7, Section 9.9.2.2.4). The degrees of track curvature, c [degree], is defined as 5730 [ft] / radius [ft] (*SME Mining Engineering Handbook*, Page 18-4, Reference 2.2.11). Therefore, the degree of track curvature, c, is calculated as 28.65 [degree], rounded up to 30 [degree]. This equation does not prove that the TEV will not derail while traveling a curve, but does show how much effort is needed to overcome the resistances while traveling around the curve. In this scenario the grade terms of the equation drop out, as well as the trailing resistance terms.

Where:
W, T = 300 [ton], from Section 6.6.3.5.
R_w = 20 [lb./ton], from Assumption 3.2.12.
a = 0.2 [mph/sec^2], from Assumption 3.2.12.
A = 100 [lb./ton/mph/sec^2], from Assumption 3.2.12.
c = 30 [degree], from within this section
C = 0.8 [lb./ton/degree], from Assumption 3.2.12.

$$TE\_Curve = W \cdot R_w + T \cdot a \cdot A + T \cdot c \cdot C$$

$$= 300. \cdot ton \cdot 20 \cdot \frac{lb}{ton} + 300. \cdot ton \cdot .2 \cdot \frac{mph}{sec^2} \cdot \frac{100 \cdot \frac{lb}{ton}}{\frac{mph}{sec^2}} + 300. \cdot ton \cdot 30 \cdot degree \cdot .8 \cdot \frac{lb}{ton \cdot degree}$$

$$= 19200. \cdot lb$$

Tractive effort on a grade with a curve

To calculate the tractive effort up a grade with curve, the TEV must negotiate a 1000-ft (305-m) radius curve (Reference 2.2.5, Figure 3). The degrees of track curvature, c [degrees], is defined as 5730 [ft] / radius [ft] (*SME Mining Engineering Handbook*, Page 18-4, Reference 2.2.11). Therefore, the degree of track curvature, c, is calculated as 5.73 [degrees], rounded up to 6 [degrees]. This equation does not prove that the TEV will not derail while traveling a curve, but does show how much effort is needed to overcome the resistances while traveling around the curve.

Where:
W = 300 [ton], from Section 6.6.3.5.
R_w = 20 [lb./ton], from Assumption 3.2.12.
T= W
g = 2.5 [%grade], from Reference 2.2.7, Section 9.9.2.2.4.
G = 20 [lb./ton/%grade], from Reference 2.2.11, Section 14.
a = 0.2 [mph/sec^2], from Assumption 3.2.12.
A = 100 [lb./ton/mph/sec^2], from Assumption 3.2.12.
c = 6 [degree], from this section
C = 0.8 [lb./ton/degree], from Assumption 3.2.12.

$$\text{TE\_Curve\_Grade} = W \cdot R_w + T \cdot g \cdot G + T \cdot a \cdot A + T \cdot c \cdot C$$

$$= 300.\cdot \text{ton} \cdot 20 \cdot \frac{\text{lb}}{\text{ton}} + 300.\cdot \text{ton} \cdot 2.5 \cdot \%\text{grade} \cdot 20 \cdot \frac{\text{lb}}{\text{ton} \cdot \%\text{grade}} + 300.\cdot \text{ton} \cdot .2 \cdot \frac{\text{mph}}{\text{sec}^2} \cdot \frac{100 \cdot \frac{\text{lb}}{\text{ton}}}{\frac{\text{mph}}{\text{sec}^2}} + 300.\cdot \text{ton} \cdot 6 \cdot \text{degree} \cdot .8 \cdot \frac{\text{lb}}{\text{ton} \cdot \text{degree}}$$

$$= 28440.\cdot \text{lb}$$

The tractive effort on the grade with a curve has the largest value and is used to determine the horsepower.

6.7.3 Horsepower

Horsepower is found by the following formula from the *SME Mining Engineering Handbook*, Page 14-11 (Reference 2.2.11, Equation (9)). The maximum recommended "Fast" speed for the TEV is 150 [fpm] (Reference 2.2.2, Table 5333.1-1) which converts to 1.705 [mph]. Therefore, the motors have been sized to provide a maximum climbing speed of 1.705 [mph].

$$HP = \frac{(TE)(MPH)}{375 \cdot \text{eff}} \qquad \text{Equation 3}$$

Where:

TE = tractive effort, 28,440 [lb.] from previous section
MPH = speed, 1.705 [mph]
Conversion_Factor = 375 [lb.-mph/hp]
eff = an efficiency factor to account for the losses in the drivetrain, 0.94, see Assumption 3.2.11.

$$HP = \frac{TE \cdot MPH}{Conversion\_Factor \cdot eff}$$

$$= \frac{28440 \cdot lb \cdot 1.705 \cdot mph}{375 \cdot \frac{lb \cdot mph}{hp} \cdot 0.94}$$

$$= 137.5609 \cdot hp$$

Since eight wheels will drive the TEV, the total horsepower is divided by eight.

$$HP\_per\_Wheel = \frac{HP}{number\_of\_wheels}$$

$$= 17.19511 \cdot hp$$

The next commercially available motor size is a 20 [hp] motor. The weight, efficiency, and gearbox width are discussed in Assumption 3.2.11.

6.7.4 Output Speed

The motor and gearbox combination must be capable of moving the TEV at nominal operating speed within the design requirement limits. The TEV max operating “Fast” speed is 150 [ft/min] from ASME NOG–1–2004 (Reference 2.2.2, Table 5333.1-1) with a wheel diameter of 36 [in], (Assumption 3.2.16). The output speed of the gearbox needs to be:

$$output\_speed = \frac{TEV\_max\_Velocity}{\pi \cdot Wheel\_diameter}$$

$$output\_speed = 15.915 RPM$$

The motor and gearbox combination discussed in Assumption 3.2.11 provides a maximum output speed of 17 RPM at a maximum torque of 72,200 [lb.-in], which is sufficient.

6.8 Envelope for TEV

6.8.1 TEV Length

The length of the TEV has already been calculated in Section 6.4.3.8, length of TEV chassis beam. The length is 320 [in.]. An additional length of 36 [in.] is added to the calculated length to account for the shield door and base plate drive systems with associated fabrications not yet designed, bringing the bounding length to 356 [in.].

6.8.2 TEV Width

The TEV width is calculated by adding the width of the chassis beams, the gearbox width, and the external width of the shielded enclosure.

Where:
Shielding_External_Width =109.70 [in.], from Section 6.2.3.2
Clearance = 2 [in.], from Assumption 3.2.1
Chassis Beams = 20 [in.], from Assumption 3.2.7
Gearbox Width = 15 [in.], from Assumption 3.2.11

TEV_Width = 15 [in.]+20 [in.]+2 [in.] +109.70 [in.] +2 [in.]+ 20 [in.]+ 15 [in.] = 183.70 [in.]
Rounded to 184 [in.] and this is a bounding width.

6.8.3 TEV Height

The TEV height can be found by adding the height above rail clearance to the height of the shielding, plus an extra 10 inches for the top chassis support. It is anticipated that the height could increase due to miscellaneous components: lights, cameras, etc.

Travel_Clearance = 2 [in.], from Assumption 3.2.1
Height of the shielding = 118.49 [in] from Section 6.2.3.3.
Side_Frame_Clearance = 2 [in.], from Assumption 3.2.1.
Crossbeam height = 10 [in.], from Assumption 3.2.7.

TEV height = 2 [in.] + 118.49 [in.] + 10 [in.] + 2 [in.] = 132.49 [in.]
Rounded to 133 [in.] and this is a bounding height.

6.8.4 TEV Open Length

The open length of the TEV is the length of the doors in an open position plus the length of the shielding multiplied by 2 plus the diameter of the shielded base plate wheels, plus some miscellaneous clearances (Figure 10).

Figure 10: TEV Open Length

Where:
Shielding_External_Length = 272 [in.], from Section 6.2.3.1.
Beam_Width = 20 [in.], from Assumption 3.2.7.
Shielding_External_Width =109.70 [in.], from Section 6.2.3.2.
Bottom_Shield_Wheel = 28 [in.] diameter, Assumption 3.2.16
Hinge = 5 [in.], from Assumption 3.2.9.
Shield_Thickness = 10 [in.], from Section 6.2.1.1.
Clearance = 2 [in.], from Assumption 3.2.1.

$$\begin{aligned}
\text{Open_Door_Length} &= \text{Beam_Width} + \frac{\text{Shielded_Enclosure_External_Width}}{2} \\
&= 20 \cdot \text{in} + \frac{109.70 \cdot \text{in}}{2} \\
&= 74.85 \cdot \text{in}
\end{aligned}$$

$$\begin{aligned}
\text{TEV_Open_Length} &= \text{Open_Door_Length} \ldots \\
&\quad + \text{Hinge} \ldots \\
&\quad + \text{Shielded_Enclosure_External_Length} \ldots \\
&\quad + \text{Clearance} \ldots \\
&\quad + \text{Back_Shield} \ldots \\
&\quad + \text{Shielded_Enclosure_External_Length} \ldots \\
&\quad + \text{Clearance} \ldots \\
&\quad + \text{Bottom_Shield_Wheel} \\
&= 74.85 \cdot \text{in} + 5 \cdot \text{in} + 272. \cdot \text{in} + 2 \cdot \text{in} + 10 \cdot \text{in} + 272. \cdot \text{in} + 2 \cdot \text{in} + 28 \cdot \text{in} \\
&= 665.9 \cdot \text{in}
\end{aligned}$$

Rounded to 666 [in.] and this is a bounding open length.

7 RESULTS AND CONCLUSIONS

7.1 The TEV internal shielding dimensions are:

Length: 252 [in.], from Section 6.1.3.1.
Width: 89.70 [in.], from Section 6.1.3.2.
Height: 98.49 [in.], from Section 6.1.3.3.

7.2 The TEV external shielding dimensions are:

Length: 272 [in.], from Section 6.2.3.1.
Width: 109.70 [in.], from Section 6.2.3.2.
Height: 118.49 [in.], from Section 6.2.3.3.

7.3 The weight of the TEV Shielding is 125.2 [ton], from Section 6.6.3.2.

7.4 Section 6.4 confirmed the assumptions regarding the TEV chassis beam. A 20 [in] by 20 [in] beam with a 1.5 [in] wall thickness is ample to carry the load of the shielding, waste package, and pallet.

7.5 Four-100 [ton] normal lift mechanisms are capable of carrying 47. 3[tons] over a 20 [in] lift. To achieve this, the normal lifting mechanisms are driven by a 12.5 [hp] motor (Section 6.5.3.2). These components are commercially available.

Two-150 [ton] off-normal lift mechanisms are capable of carrying 94.5 [tons], over a 20 [in] lift. To achieve this, the off-normal lifting mechanisms are driven by a 12.5 [hp] motor (Section 6.5.3.3). These components are commercially available.

7.6 The weight of an empty TEV is 367,430 [lb.] or about 183.7 [ton], from Section 6.6.3.3. The weight of a loaded TEV is 551,130 [lb.] or about 275.6 [ton], from Section 6.6.3.4.

7.7 The TEV will be driven through eight gearboxes by eight motors that are capable of producing 20 [hp] each (Section 6.7). This gearbox and motor combination is commercially available.

7.8 The overall bounding envelope dimensions for the TEV is:

TEV Length = 356 [in], from Section 6.8.1.
TEV Width = 184 [in], from Section 6.8.2.
TEV Height = 133 [in], from Section 6.8.3.
TEV Open Length = 666 [in], from Section 6.8.4.
TEV Loaded Weight = 300 [ton], from Section 6.6.3.5.

ATTACHMENT 1 – CONCEPTUAL SKETCH TO INDICATE TEV MAJOR COMPONENTS